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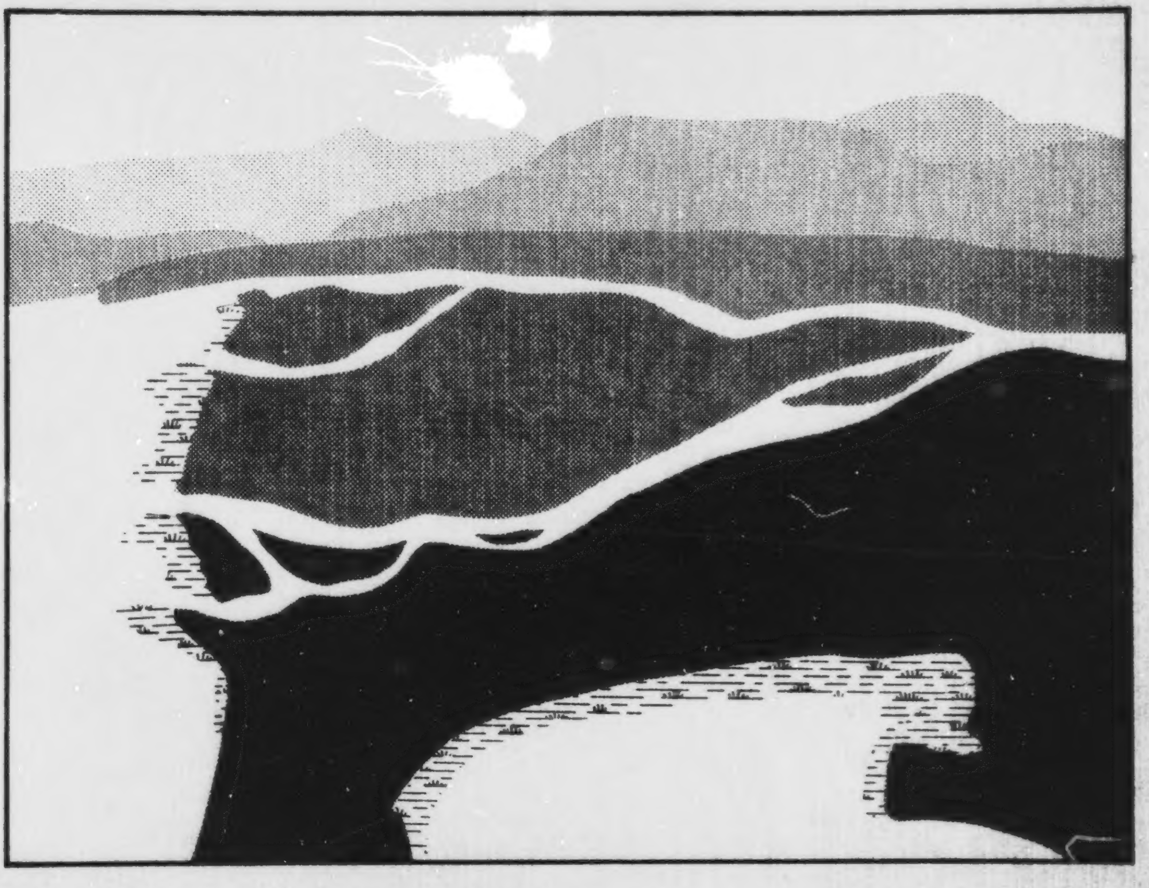
ENVIRONMENTAL IMPACT ASSESSMENT OF CONSTRUCTION OF A NATURAL GAS PIPELINE ACROSS ROBERTS BANK



Volume 1: Summary

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BC Hydro
February, 1983

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ENVIRONMENTAL IMPACT ASSESSMENT OF CONSTRUCTION OF A NATURAL GAS PIPELINE ACROSS ROBERTS BANK

VOLUME I - SUMMARY

B. C. Hydro
February 1983

CR26B

ADDENDUM

FEBRUARY, 1983

CR28F

ADDENDUM

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1.0 INTRODUCTION

This addendum has been prepared following the review of the five volume report entitled Environmental Impact Assessment of Construction of a Natural Gas Pipeline Across Roberts Bank by the Order-In-Council 908 Environmental Assessment Committee. The review process covered the period between February and October, 1982, during which time several major concerns about the potential impacts of the project were reviewed by the Committee, B. C. Hydro, and its consultants.

This document is intended to describe the significant changes in the proposed method, sequence and timing of pipeline construction on Roberts Bank that have resulted from the review process, and to summarize the nature of the key issues that were raised by the Committee and Hydro's responses to them.

It is recognized, however, that until approval for the project as a whole is obtained, and approval for the construction of the pipeline across Roberts Bank is granted by the Minister of Environment under OIC 908, that any conditions attached to those approvals may alter the proposed sequence and/or timing of construction, and consequently the nature and severity of any associated environmental impact.

The conclusions reached in the original impact assessment, and those derived following the review process, therefore, are only valid for the project as it is now proposed; any significant departures from this, particularly with regard to the timing of construction, may alter the conclusions reached and possibly render the proposed mitigation measures inappropriate.

In the impact assessment, the analysis of potential impacts associated with various construction sequences and schedules resulted in a preference for a landwards sequence, starting at the delta foreslope on June 15 and proceeding landwards to Brunswick Point where the tie-in with the land pipeline would be made.

The reasons for adopting this sequence and schedule are described in detail in the impact assessment report, along with the various assumptions that were inherent in the impact analysis.

Subsequent discussions with the Committee identified several points of major concern, particularly regarding the sequence and timing of the dredging operation, as the greatest opportunity for avoiding or minimizing potential impacts of pipeline construction lies in the adjustment of the construction schedule. The following section describes these concerns and Hydro's responses to them. Several other minor points of concern were also raised by the Committee in their review of the impact assessment; these have been incorporated into the final drafts of the impact assessment reports, where applicable.

2.0 MAJOR REVIEW COMMENTS AND B. C. HYDRO'S RESPONSE

2.1 Brunswick Point Marsh

One of the significant potential impacts that was identified in the impact assessment was that of pipeline construction through a fringe of the marsh at Brunswick Point. At that time, Hydro's preferred route crossed the northeast corner of the marsh, and would have resulted in the disturbance of approximately 2.4 hectares of marsh. Proposals for restoring the marsh were presented as a means of mitigating this impact.

Alternative routes were considered during the impact assessment, but were rejected as none offered any significant advantages in terms of potential impacts, ease of construction and costs. The Committee, however, held the view that the environmental benefits of avoiding the marsh, and the cost savings of not having to restore the marsh would outweigh the technical disadvantages and extra costs of bringing the pipeline ashore farther upstream in Canoe Pass.

In the summer of 1982, Hydro reviewed the possibility of relocating the shore approach upstream of the marsh, and the location of the valve station and pipeline inside the dyke. At that time, it was learned that the B. C. Harbours Board, owners of the old cannery site at Brunswick Point, planned to demolish the cannery and the ancillary buildings later in 1982 and 1983 respectively. Given these new circumstances, Hydro inquired as to whether or not this site could be made available for the pipeline landing. Use of this site, which is slightly upstream of the marsh, would mean that the pipeline could be routed so as to almost entirely avoid the marsh, thus greatly reducing any potential impacts on this area, and virtually eliminating the need for marsh restoration.

Discussions with the B. C. Harbours Board indicated that the use of the cannery site was broadly acceptable to them, subject to Hydro obtaining the requisite approvals for construction and agreement on terms and conditions.

Figure A-1 shows the shore approach arrangement that is now proposed at Brunswick Point. This information has been presented to the Committee, but to date confirmation has not been received as to whether the revised routing is acceptable.

2.2 Dyke Access

The Committee raised some concern regarding the safe restoration of the dyke and maintaining access along the dyke during and after construction. The method of installing the pipeline through the dyke has been described in detail in Volume 2 of the Environmental Impact Assessment. Hydro is committed to restoring the dyke to its original condition and meeting all the requirements of the Inspector of Dykes.

There is a gravelled path which provides public access along the dyke to the west of the cannery site. Relocation of the shore approach to the cannery site will have little or no effect on public access to or along the dyke, because it will still be possible to reach the dyke by skirting around the cannery site during construction of the shore approach. In any case, the dyke will only be breached for a short period of time, and road access will be maintained around the site during construction as required by the Inspector of Dykes.

2.3 Construction Schedule and Sequence

Several options for the construction sequence and schedule were considered in the impact assessment, and after considering the advantages and disadvantages of each, Hydro adopted the landward sequence as its preferred scheme. Recognizing the various environmental constraints on dredging activity on Roberts Bank and in Canoe Pass, Hydro proposed to start dredging at the head of the foreslope on June 15. This schedule would allow completion of dredging by December 31, and provide a 60 day contingency period in the event that a major delay in the dredging operation occurred. The reasons for adopting this schedule, the underlying assumptions and the potential impacts associated with it have been described in detail in the Summary Volume of the impact assessment.

One of the critical assumptions concerned the timing of the annual downstream migration of juvenile salmon. As juveniles can become entrained by suction dredges, it was considered imperative that the dredging operation avoid the period of the downstream migration. The migration generally starts in early March and tapers off by the end of May. It was assumed, therefore, that dredging would have to be completed by the end of February. This date was confirmed for planning purposes during discussions with the Department of Fisheries and Oceans, recognizing that there can be some annual variance in the actual timing of the migration period.

2.3.1 Dredging Start Date

The proposed start date for dredging, June 15, was based on use of a 26 inch dredge, an assumed rate of production for that size of dredge, allowance for weather downtime, and a 60 day contingency. At that time, it was known that 26 inch dredges were readily available locally, whereas the availability and mobilization costs of larger capacity dredges (which would reduce the time required for the job) were uncertain. It was recognized that there would be some risk of juvenile fish kill, but it was considered preferable to incur a lower risk of fish mortality during the mid to late summer than a higher risk that would be incurred if the start of dredging was delayed until the late summer and extended into the downstream migration period in the early spring when the dredge would be operating within the confines of Canoe Pass.

The Committee considered that if pipeline construction was permitted to start at the foreslope as early as June 15, there would still be a significant impact on juvenile fish on Roberts Bank, and would also result in a significant disturbance to waterfowl in the late fall and winter. The Committee favoured a dual spread sequence, with the landwards spread starting at the foreslope on September 1, and the seawards spread starting at Brunswick Point in July or August.

After considerable discussion of these concerns with the Department of Fisheries and Oceans, it was confirmed that their primary concern is with the potential impact on juvenile salmon, and that in the absence of sufficient information on the pattern of fish use on Roberts Bank, they would maintain a conservative position and recommend that dredging not be permitted prior to September 1.

2.3.2 Fish Sampling Program

In July, August and September of 1982, Hydro contributed funds to a fish sampling survey on Roberts Bank, undertaken by the Department of Fisheries and Oceans, to obtain data on the density and distribution of juvenile salmon on Roberts Bank in the vicinity of the pipeline route. The results of this survey are contained in Appendix B to this Addendum; in broad terms, they showed a marked decline in fish densities in August and September.

Subsequent discussions with the Department indicated that the results justified a start date as early as August 1, subject to monitoring of fish prior to the start of dredging. The Department was not prepared to consider an earlier start date than August 1 because their sampling surveys at the Roberts Bank Coal Port indicated that substantial numbers of juveniles were using the banks in July. It was agreed, however, that if Hydro wished to undertake further surveys in the June-September period of 1983 to obtain more information on the pattern of juvenile fish distribution along the pipeline route for that period, there would be no objections.

In conclusion, therefore, it is Hydro's understanding that from the point of view of fisheries management, an acceptable dredging "window" exists for planning purposes between August 1 and February 28, but that the actual start date in the year of construction may vary depending on the results of fish monitoring surveys prior to the start of dredging, and the completion date may be varied to accommodate the downstream migration.

2.3.3 Crabs

Recent surveys of crab populations along the Roberts Bank foreslope, carried out by the Department of Fisheries and Oceans showed that there is a significant crab population along the foreslope, particularly at the mouth of Canoe Pass. The migration patterns of crabs during the year are not well understood, therefore, it was considered not possible to define the potential impacts on crabs resulting from changes in construction timing. It was recognized that the costs of delaying the start of dredging to avoid the annual soft-shell period would be far greater than the value of the potential loss of crabs.

Hydro recognizes that crab mortality will result from the dredging operation and is prepared to undertake mitigative measures to reduce this loss, such as a program of intensive trapping of crabs prior to construction to move crabs away from the pipeline route, if this is considered useful. Hydro believes that the benthic community along the pipeline route will re-establish itself within one year, and presumably crabs would, therefore, recolonize the area.

2.3.4 Waterfowl

The potential disturbance to waterfowl as a result of the construction activity near Brunswick Point was of considerable concern to the Committee. In part, it was for this reason that the Committee favoured the use of a dual spread sequence that would have resulted in the inshore section of the route being constructed during the summer, thereby minimizing disturbance to waterfowl which winter in the area.

Hydro provided the Committee with more detailed information on the expected noise levels associated with the dredging operation, and the anticipated nature and frequency of local traffic associated with servicing single and dual construction spreads. If two spreads were used, there would inevitably be a higher volume of boat traffic operating in and out of Canoe Pass during the early part of the sensitive period than with a single spread sequence but construction would probably be completed sooner. Hydro considered, therefore, that the disturbance to waterfowl associated with a dual spread operation would be no less, and possibly significantly greater, than with a single spread operation.

2.3.5 Dredge Size and Availability

In light of the environmental constraints and major concerns raised during the review of the impact assessment, it became clear that the proposed June 15 start date was unacceptable to the Committee. B. C. Hydro has reviewed its dredging program assuming a construction window between August 1 and February 28, which is understood to be acceptable for planning purposes to the Committee. This window encompasses 212 calendar days.

Hydro originally proposed to use a 26 inch diameter dredge as dredges of this size were known to be available in the Lower Mainland area, would allow competitive tendering, and could complete the job at a reasonable cost and allow for a reasonable contingency period if the start date was no later than June 15. A dredge of this size, however, could not complete the job before February 28 (212 days) if an August 1 start date were used and a 60 day contingency period was still required.

Consequently, Hydro examined several alternative dredging schemes that would complete the program within 212 days and still allow for a minimum 60 day contingency period. Although it was recognized at the start of this study that a dredge with a higher rate of production would complete the job more quickly, no large dredges (36") were available in British Columbia at that time, and the costs of importing such a dredge would be extremely high. Since then, however, a 36 inch dredge has been moved to the coast to work on the Roberts Bank Coal Port expansion, and may be available at the time of construction of the pipeline. If it is assumed that this dredge is available, it would be possible to complete the job within the designated construction window from August 1 to February 28 using a landwards sequence and allowing for a 60 day contingency period based on average production rates.

An independent review of the feasiblity of constructing the pipeline within the time frame allowed, using the "bathtub" method of constuction, was undertaken by Volker Stevin Dredging Ltd. Their review confirmed the feasibility of using the "bathtub" method of construction on Roberts

Bank and concluded with slightly more conservative estimates of the time required to complete the dredging, due to assumed lower production rates (32 inch dredge) and higher frequency of weather downtime.

Hydro concluded that the latest start date for the landwards sequence, assuming a 36 inch dredge and allowing for a 60 day contingency period, is August 1. Figure A-4 shows the proposed construction schedule based on this start date. At the same time it is recognized, however, that an earlier start date would allow for a greater contingency period and reduce the risk of running out of time as the February 28 deadline is approached. Furthermore, the longer the construction period allowed, the more imaginative and numerous would be the bids, thus ensuring a more competitive bidding process. B. C. Hydro considers the 60 day contingency period to be the minimum allowable given winter conditions in the study area, typified by the occurrence of storms such as that of December 14-20, 1982, during which time the dredge was unable to operate.

3.0 CONCLUSIONS

3.1 Sequence and Schedule

After considerable review of alternative construction sequences and schedules, Hydro concluded that the construction scheme that offered an acceptable level of environmental impact within a reasonable cost and time frame work is a landwards sequence, with dredging starting at the foreslope no later than August 1 and completed by 28th February. Hydro favours an earlier start date, however, and requests that the start date be advanced if it can be shown that there are sufficiently low numbers of juvenile salmon in the vicinity of the pipeline route prior to August 1. Hydro proposes, therefore, to closely monitor fish distribution on Roberts Bank prior to August 1 in the years prior to construction in conjunction with the Department of Fisheries & Oceans, to determine if the start date could be advanced.

Hydro recognizes the importance of completion of construction by 28 February for reasons of environmental impact, cost, and planning for the initial delivery of gas in the system. The importance of completion has to be considered at the time of tendering for construction. Hydro proposes, therefore, to include the following provisions in the tender documents directed towards achievement of completion by 28 February.

1) Tenderers may propose either a single spread with a landward sequence of construction, or a dual spread.

2) The tenderer will be required to provide within his tender, details of the contingency plan, or plans, which could be adopted at various times to ensure completion of the project by 28th February. It is most probable that a single spread operation could only be proposed with use of a 36 inch dredge which would allow for an ample contingency period.

3.2 Loss of Crabs

It is recognized that dredging at the foreslope will result in some crab mortality, but that this impact is relatively insensitive to timing. It is believed that crabs will recolonize the area after construction, particularly as it is expected that the benthic community along the pipeline route will re-establish itself within one year, and will, therefore, continue to be an available food source for crabs. To reduce the loss of crabs during the dredging operation, Hydro is prepared to implement a crab trapping program along the pipeline route prior to dredging, with release of the crabs at an area remote from the path of dredging, if this is considered useful. It would presumably reduce crab mortality within the construction zone.

3.3 Waterfowl Disturbance

Hydro's preferred sequence and schedule is such that the construction spread will be approaching Canoe Pass and the more sheltered, inshore area near Brunswick Point during the late fall and winter (see Figure A-5). This timing coincides with the peak period of waterfowl use, and for this reason, considerable attention has been given to the effects of construction activity on these birds. Hydro believes that with the landward sequence there is considerably less danger of oil spills as the construction train will be in more sheltered waters during the period from December through February.

To date, there is no clear understanding of the effects of noise and disturbance from pipeline construction on waterfowl, although Hydro has been advised by its consultant that these effects are unlikely to constitute a significant impact, and are only temporary. Due to the uncertainty of the nature of these impacts and the concern expressed by the Canadian Wildlife Service, Hydro proposes the following mitigative steps:

1) to reduce the level of disturbance from service and supply boats, Hydro will limit the boat traffic seaward of the "bathtub" after November 1 to daylight hours only, and restrict the use of helicopters to medical emergencies and such times as tide conditions prevent access to the construction train (ie. extreme low tides). This would reduce disturbance created by the service and supply boats, and, if construction proceeds as scheduled and the laybarge is in Canoe Pass by November 1, will result in less than normal disturbance from boat traffic because Canoe Pass would be blocked off.

2) Hydro will implement bird monitoring studies, provided that such studies can be shown to assist in determining the effects of construction on waterfowl, and lead to further mitigative efforts, if required.

3.4 Dredge Operating Hours

Hydro is unwilling to restrict the daily operating period of the construction spread to daylight hours when it approaches Brunswick Point due to the overiding concern that the dredging be completed by February 28. Assuming a landwards sequence, the construction spread would be approaching Brunswick Point in late December; however, if there were any significant delays in the construction program, there would be a risk of not completing the job before the end of February. It was considered, therefore, that any restrictions on the hours of operation of the dredge, as was suggested by the Municipality of Delta as a means to eliminate noise during the nightime, would only increase the risk of failing to complete the job prior to the end of February . As there are only six to eight residences within 1 km of Brunswick Point, and the noise levels are expected to increase from approximately 40-50 dBA to 60 dBA, a level that is typical for an urban residential area, the restricted hours of operation do not seem justifiable.

3.5 Marsh Restoration

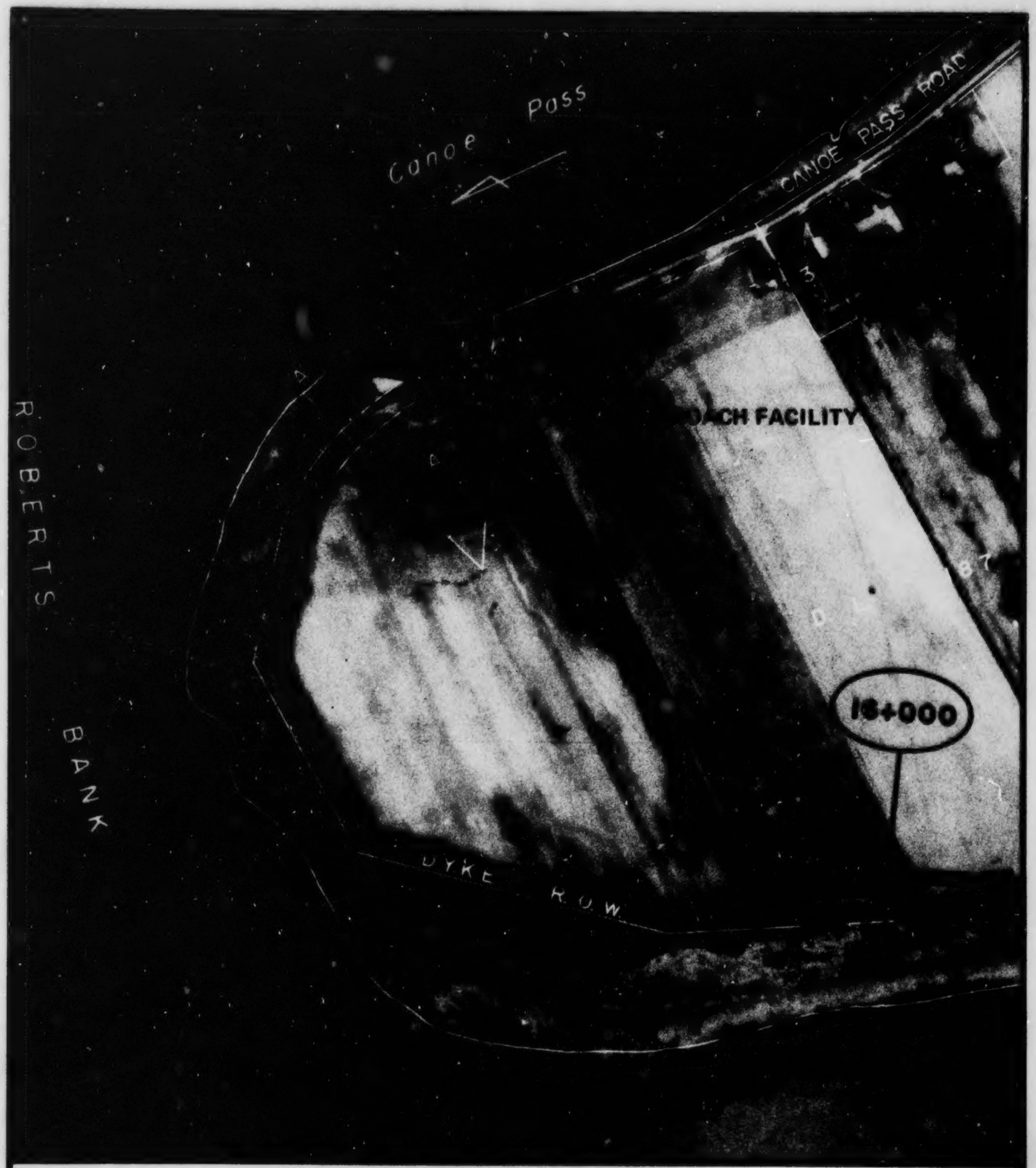
As explained previously, and shown on Figure A-1, Hydro proposes to bring the pipeline ashore at the site of the Brunswick cannery, just upstream of the Brunswick Point marshes. The route as proposed will almost completely avoid the marsh vegetation, therefore the impacts on the marsh are expected to be negligible. If, for any reason, construction activity impacts the marsh, Hydro is committed to restoring the marsh to its original condition.

3.6 Sources of Backfill

When the 'bathtub' reaches the Brunswick Point shore approach, fill must be taken from adjacent areas to fill it. For the single spread sequence, approximately 220,000 m^3 of material would be needed, and it is proposed to dredge this material from the bottom of Canoe Pass channel and from sandbanks adjacent to Brunswick Point. Figures A-2 and A-3 show the locations and profiles of the proposed borrow areas in Canoe Pass. The sandbanks would not be entirely removed as it is recognized that these are used as loafing areas for birds. Northwest Hydraulic Consultants have confirmed that the dredging in Canoe Pass channel would not significantly affect the hydraulics of the channel.

3.7 Dyke Access

The proposed shore approach would breach the dyke at the site of the old cannery. Public access to the dyke will not be significantly affected by pipeline construction because it will still be possible to walk around the cannery site where the shore approach facilities will be installed, using the existing road. The dyke will be restored to its orginal condition once the pipeline has been installed.


Canoe Pass
CANOE PASS ROAD
3
2
ACH FACILITY
ROBERTS
BANK
D.L.
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DYKE R.O.W.

BRUNSWICK POINT
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Figure A - 1

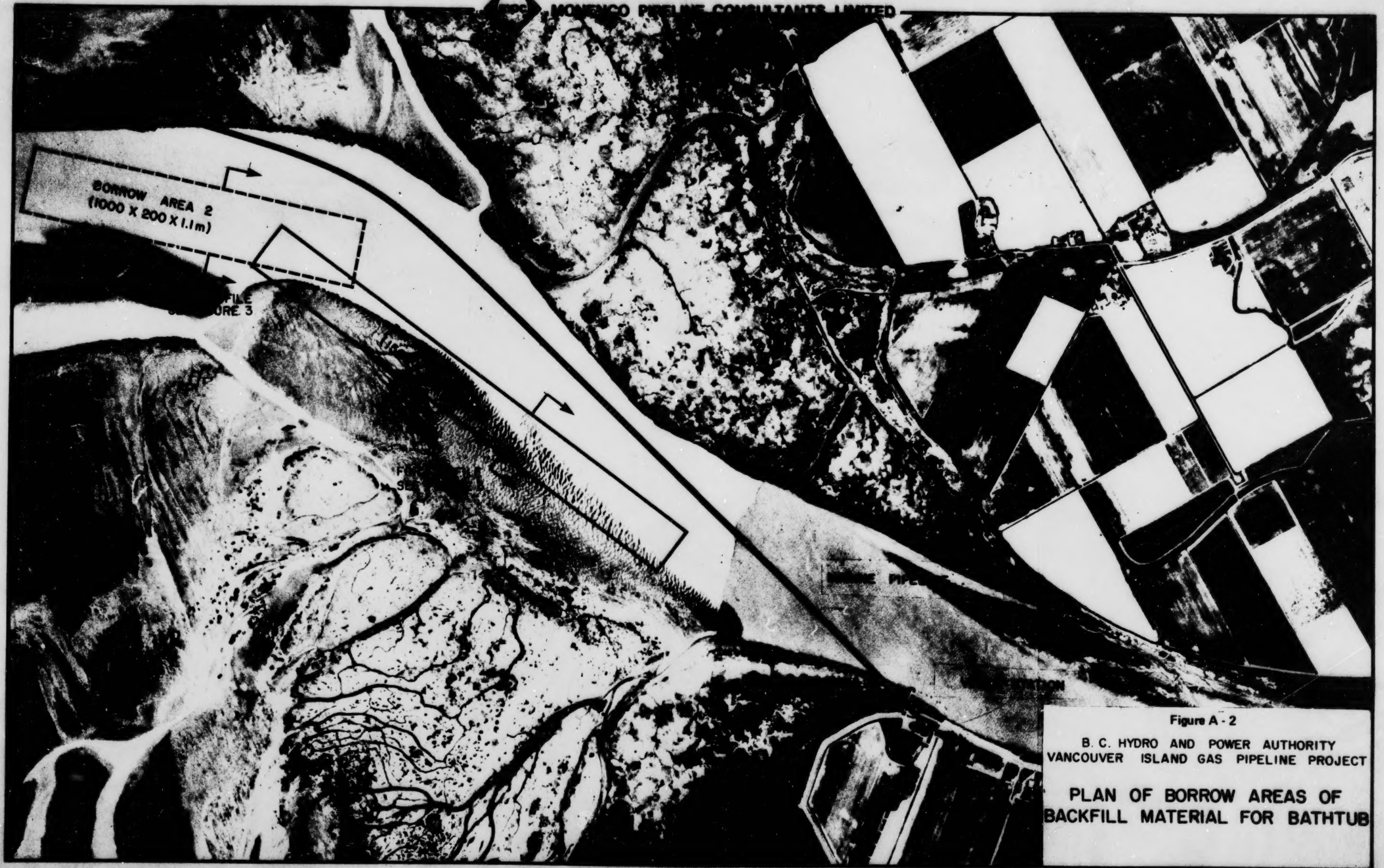
BORROW AREA 2
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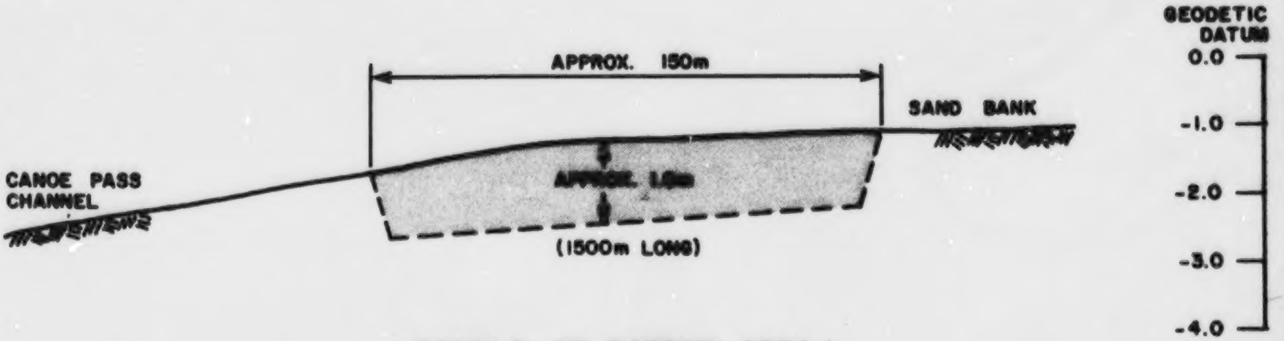
Figure A - 2

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

PLAN OF BORROW AREAS OF BACKFILL MATERIAL FOR BATHTUB

MONENCO PIPELINE CONSULTANTS LIMITED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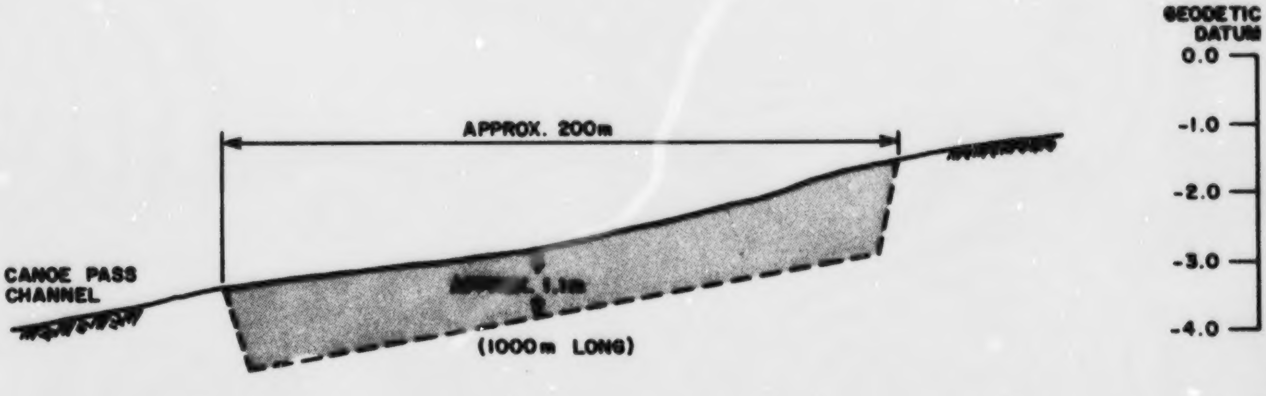
-3.0
-4.0
APPROX. 150m
SAND BANK
CANOE PASS CHANNEL
APPROX. 1.0m
(1500m LONG)

PROFILE OF BORROW AREA 1
(SAND BANKS ADJACENT CANOE PASS)

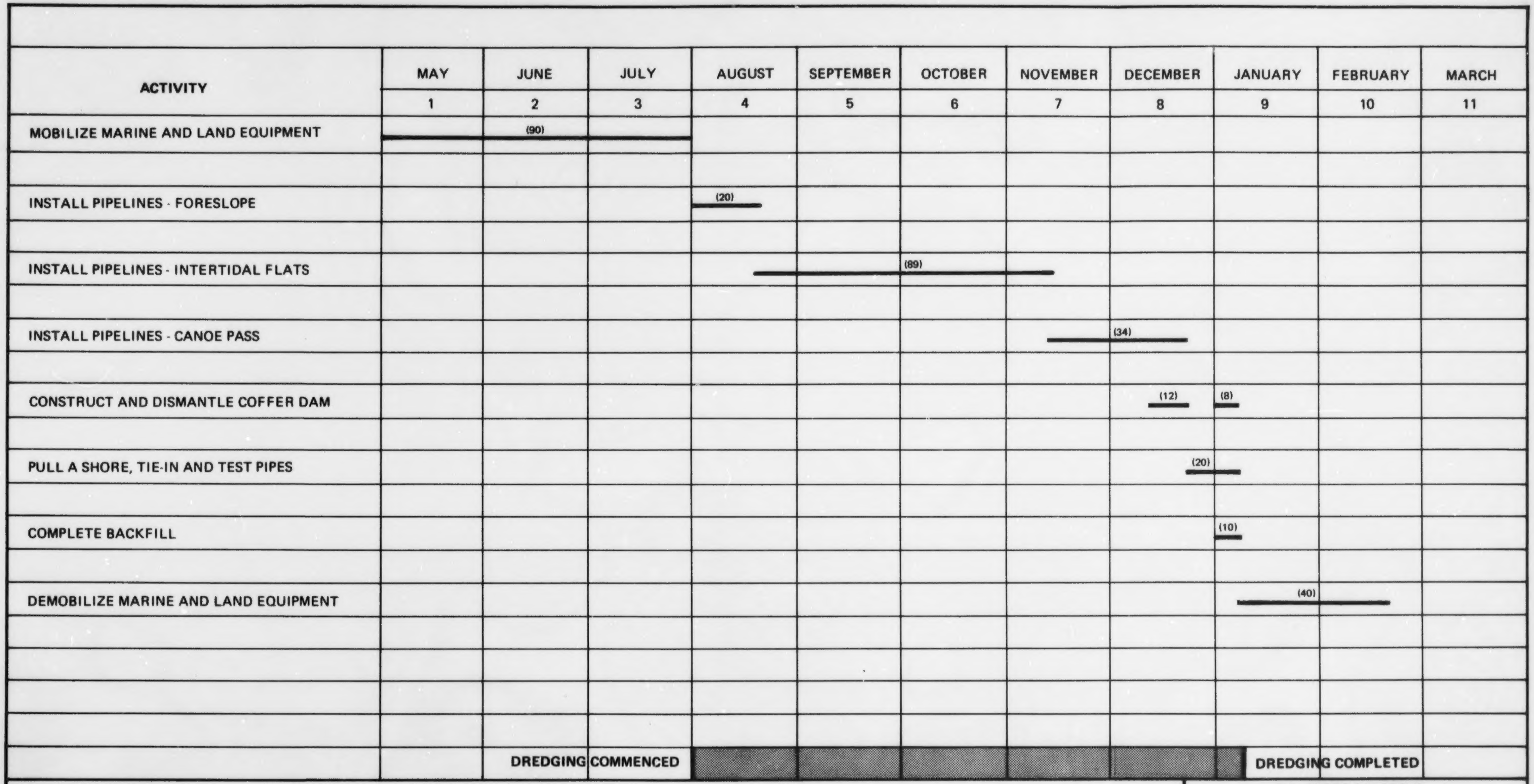

GEODETIC DATUM
0.0
-1.0
-2.0
-3.0
-4.0
APPROX. 200m
CANOE PASS CHANNEL
APPROX. 1.1m
(1000m LONG)

PROFILE OF BORROW AREA 2
(CANOE PASS)

Figure A - 3

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

PROFILES OF BORROW AREAS 1 AND 2



( ) NUMBER OF CALENDAR DAYS

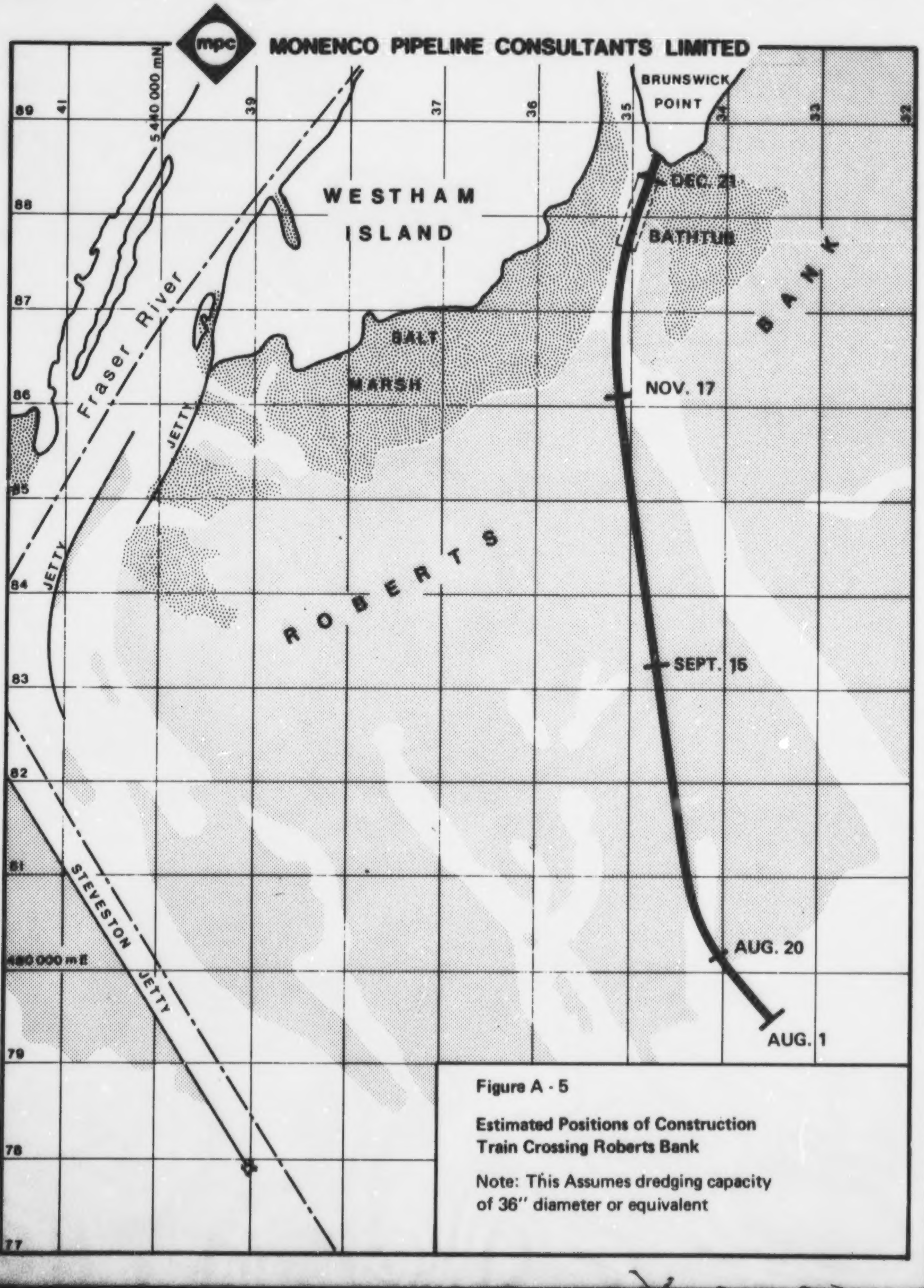
B.C. HYDRO GAS GROUP

VANCOUVER ISLAND NATURAL GAS PROPOSAL

Roberts Bank Crossing

Proposed Construction Schedule

Figure A - 4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MONENCO PIPELINE CONSULTANTS LIMITED
5 480 000 mN
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89
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39
37
36
35
34
33
32
BRUNSWICK POINT
WESTHAM ISLAND
DEC. 21
BATHTUB
BANK
Fraser River
JETTY
SALT MARSH
NOV. 17
ROBERTS
SEPT. 15
STEVESTON JETTY
AUG. 20
AUG. 1

Figure A - 5

Estimated Positions of Construction Train Crossing Roberts Bank

Note: This Assumes dredging capacity of 36" diameter or equivalent

ABSTRACT

This report presents the environmental impact assessment of the construction of that portion of the proposed natural gas transmission system across Roberts Bank as required by the Provincial Order-In-Council 908. It describes the process that lead to selection of a route for the twin pipelines across Roberts Bank, the construction method and schedule, starting at Brunswick Point, and ending at the -40 m contour on the foreslope of Roberts Bank. At this point, a tie-in with the marine pipelines crossing the Strait of Georgia would be made.

The proposed construction methods and the potential environmental impacts arising from construction are described. Analysis of a variety of possible construction methods shows that there is only one practical method of construction, and that the opportunities available to avoid or minimize adverse effects of construction are primarily associated with scheduling. Two construction sequences, landwards and seawards, and their associated schedules were analysed, and it was found that the landwards sequence allowed construction to be achieved within acceptable levels of environmental impact, and within an acceptable time frame and capital cost.

B. C. Hydro's preference is to adopt the landwards construction sequence, thereby avoiding conflict with the downstream migration of juvenile salmon in the Fraser River, and minimizing potential conflict with most other aquatic resources and use of those resources.

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SUMMARY

This report has been produced to meet the requirement of B. C. Order-in-Council 908 which is designed to protect the environment of Roberts Bank, and as a supporting document to B. C. Hydro's application for an Energy Project Certificate for the proposed gas transmission pipeline to Vancouver Island.

The report, with its appendices, describes the project and the potential impacts associated with pipeline construction. The key consideration in terms of pipeline location, design and impact assessment is the need to bury the twin pipelines 5 to 7 m below the surface of Roberts Bank to guard against possible exposure of them that could result from the lateral migration of Canoe Pass. To achieve the required burial depth, a suction dredge would be used to excavate the trench. Review of the possible construction techniques led to selection of the "bathtub method" as the preferred method of construction, whereby the suction dredge would advance along the route, followed by a shallow water laybarge and backfill barge floating in the trench, or "bathtub", created by the suction dredge. The twin pipelines are assembled on the laybarge and lowered to the bottom of the trench, and are then buried under the dredgeate deposited from the backfill barge.

This construction method reduces the opportunities for mitigating potential impacts to route location, sequence of construction, and construction scheduling. The western end of the route was largely fixed by identifying the most suitable location for descent of the delta foreslope, and at the eastern end by the route that minimized impact on the tidal marshes at Brunswick Point and Westham Island.

The selection of a construction sequence and schedule are closely linked. The main objective in planning the dredging program is to avoid conflict between dredging and the downstream migration of juvenile fish from the Fraser River. The latter occurs between the beginning of March and the early summer.

The seawards construction sequence would involve start-up of dredging in Canoe Pass after the downstream migration, thereafter continuing seawards. It would mean that the work in the deepest water near the head of the foreslope would be done during the period of worst weather.

The landwards sequence of construction would start at the head of the foreslope in June and proceed landwards, completing all dredging in Canoe Pass by the end of December, and would leave a 60 day contingency period prior to the start of the downstream migration of juvenile salmon.

The landwards sequence is preferred as winter construction would occur inshore in a more sheltered area, with correspondingly lower risks to men and equipment. It is also preferred on environmental grounds as the disturbance of the marsh at Brunswick Point will occur during the plant dormancy period. It is recognized that work in Canoe Pass and the marsh during late fall and winter would result in localized disturbance of wintering waterfowl and some disruption of hunting and bird watching activities which are popular at Brunswick Point and in the adjacent marshes. The seaward sequence would not create any significant direct disturbance to wintering waterfowl.

The major environmental and social impacts that are foreseen, assuming the landwards sequence of construction, are:

- Intake, mixing and discharge of trench spoil in a different pattern of stratification with losses of about 250,000 m^3 of fine silts.

- Loss of benthic populations in dredged area for about one year before recolonization is complete. Potential toxic contaminants, such as heavy metals, hydrogen sulphides, etc., will not be released during dredging in amounts sufficient to harm aquatic resources.

- Dumping of spoil from initial dredging on the foreslope, resulting in burial of benthic organisms and possibly some crab mortality.

- Interference with commercial salmon fishery on Roberts Bank.

- Disturbance of wintering waterfowl near Canoe Pass.

- Extra costs in travel time to commercial fishermen from blocking of Canoe Pass during late fall and winter.

- Disturbance of 2.4 ha of tidal marsh at Brunswick Point.

The recommendations for mitigation or compensation for project impacts are:

- Adoption of landwards construction sequence and schedule.

- Restoration of disturbed area of marsh, and monitoring of plant growth.

- Monitoring of benthic recolonization.

- Compensation for extra costs incurred by commercial fishermen due to closure of Canoe Pass.

- Construction of a small, public parking facility near the Brunswick Point valve station for hunters and other recreational users.

1.0 INTRODUCTION

1.1 Order in Council 908

The Government of British Columbia, recognizing the "significance of the commercial and sports fisheries, wildlife, recreational and aesthetic values associated with the Fraser Estuary", passed Order in Council 908 on 17 March 1977 (see Appendix 1) to ensure that an environmental impact assessment was made of every proposal for development under Provincial jurisdiction on Roberts Bank and other areas of the estuary. The Order requires the approval of the Minister of Environment of the environmental impact assessment before any permits may be issued for the project, or construction can proceed.

B. C. Hydro, recognizing that its preferred route for a gas pipeline to Vancouver Island would cross the area designated in Order in Council 908, advised the Assessment Branch of the Ministry of Environment of the need to review the environmental impacts on Roberts Bank of its proposed project on 26 November 1980.

A series of meetings between the Technical Assessment Committee for OIC 908, assembled by the Assessment Branch, with representatives from federal and provincial resource agencies and the Municipality of Delta, and B. C. Hydro led to an instruction from the Ministry of Environment on 19 February 1981 to prepare an environmental impact assessment in accordance with an agreed terms of reference. The instruction and Terms of Reference appear in Appendix 2.

1.2 Purpose of Project

The Governments of Canada and British Columbia have adopted as a major theme in their energy policies the displacement of oil, of which Canada and British Columbia are net importers, by natural gas, of which Canada and British Columbia are now exporters and have ample proven reserves.

Vancouver Island, Howe Sound and the Sunshine Coast are not presently served with natural gas, and of these areas, the Vancouver Island market has the greatest potential for displacement of oil.

Since the late 1950's, a pipeline to deliver gas to the Island has been the subject of much discussion and study. For a variety of reasons, however, natural gas service has never been extended to the Island. Primary among these were economics, local availability of cheap petroleum products, and technical difficulties. The possibility of a gas pipeline has been considered by both the Provincial and Federal Governments for some time, and was the subject of a Provincial Utility Commission (PUC) hearing in 1972. The PUC was disbanded in 1973 by the then-new NDP Government, before any decision or report on the pipeline hearings was issued.

Since that time, the situation has changed dramatically. Development of modern pipeline technology and the growth of the potential market for natural gas on Vancouver Island, coupled with rising oil prices and uncertainty of oil supply, make compelling arguments for extending natural gas service to the Island.

The transmission of gas to Vancouver Island has also been shown to benefit the provincial economy. B. C. Hydro has pursued technical, environmental and economic studies of the project to the point that it has identified, in the process described in Section 2, the most attractive route as one crossing Roberts Bank en route to Valdes and Vancouver Islands.

This study addresses the technical and environmental aspects of the project in the designated area as required by OIC 908.

1.3 Report Format and Reference Documents

This volume describes in summary form the project and the proposed construction methods, and the analysis of the impacts arising from the project. Finally, it presents recommendations and proposals for mitigation and compensation of the impacts.

The analysis of impacts is based on information contained in the reports mentioned in Section 4. These should be referred to by those readers seeking detailed information on project description or impacts.

The main references, appended to this report, are:

- Volume 2 -	Monenco Pipeline Consultants, The Impact of Pipeline Construction on the Physical Environment of Roberts Bank. 1983.
- Volume 3 -	R. U. Kistritz Consultants, The Impact of Pipeline Construction on the Aquatic Ecosystem of Roberts Bank. 1983.
- Volume 4 -	D. A. Blood & Associates, Potential Impact on Wildlife of Pipeline Construction Across Roberts Bank. 1983.
- Volume 5 -	Cypress Resource Consultants, The Potential Impact of Pipeline Construction on Public Use of Roberts Bank. 1983.

The Supplementary references, not appended to the report, but available from B. C. Hydro if necessary, are:

- Monenco Pipeline Consultants; Effect of Seismic Loading on Roberts Bank, 1982.
- Monenco Pipeline Consultants; Roberts Bank Construction; September, 1981.
- Monenco Pipeline Consultants Ltd.; Final Pipeline Design; December, 1981.
- Montreal Engineering Company Ltd.; Preliminary Assessment of Route Alternatives and Construction Techniques for Roberts Bank; 1978.
- Western Canada Hydraulics Laboratories Ltd.; Roberts Bank Hydraulic Study, Proposed Vancouver Island Pipeline; 1978.
- Western Canada Hydraulics Laboratories Ltd.; Hydraulic and Related Studies on Roberts Bank, and Review of Existing Oceanographic, Hydraulic, and Geotechnical Information on Sturgeon Bank; 1980.
- Northwest Hydraulic Consultants Ltd.; Vancouver Island Gas Pipeline, Preliminary Canoe Pass Scour Study; 1980.
- Thurber Consultants Ltd.; 1980-81 Testing Program (2 Vols.); April, 1981.
- McElhanney Surveying & Engineering Ltd.; Roberts Bank Bathymetry; September, 1980.
- Monenco Pipeline Consultants Ltd.; Test Trench Study on Roberts Bank; December, 1980.

1.4 Acknowledgements

The ecology and the nature of public use of the study area is complex and it would have been impossible to assemble the information required for impact analysis without the cooperation and assistance of the Federal and Provincial agencies having an interest in the management of Roberts Bank. Their assistance in the preparation for this study is greatly appreciated. Agencies that provided information were:

Government of Canada

Department of Fisheries and Oceans

Department of Energy, Mines and Resources
- Pacific Geoscience Centre

Environment Canada
- Atmospheric Environment Service
- Canadian Wildlife Service
- Lands Directorate

Transport Canada
- Coast Guard
- National Harbours Board
- Pacific Pilotage Authority

International Pacific Salmon Fishing Commission

Government of British Columbia

Ministry of Environment
- Assessment Branch
- Fish and Wildlife Branch
- Fraser River Estuary Study
- Inspector of Dykes

Ministry of Lands, Parks & Housing
- Land Management Branch
- Parks and Outdoor Recreation Branch

Ministry of Transportation and Highways

B. C. Harbours Board

Regional and Local Government

Greater Vancouver Regional District
- Parks Department

Municipality of Delta

2.0 HISTORY

2.1 Summary of Corridor and Route Selection Process

The B. C. Government's "Guidelines for Linear Development" were followed to determine the preferred corridor to and on Vancouver Island, and the preferred route within that corridor.

A network consisting of segments of possible corridors between Tilbury, Nanaimo, and Victoria was first identified. North of Nanaimo there is only one broad corridor, the coastal plain. The corridor network between the Lower Mainland and Vancouver Island was strongly controlled by the limited number of feasible departure points from the Lower Mainland, crossing sites of the submarine ridges east of the Gulf Islands, and landing sites on Vancouver Island.

Within each segment of this network a technically preferred route was identified and an estimate of its cost and service reliability prepared. The degree of impact of construction in each segment was then assessed, based on the impact on terrain, water and vegetation, on the resources, and resource use.

The less favourable alternatives were identified and discarded through a process of comparison of corridor segments that comprised limited portions of the network. Ten final corridor options, connecting Tilbury, Victoria, and Nanaimo, were then identified, and compared in terms of their total cost, environmental and resource impacts, and reliability.

The favoured corridor in terms of least impact, least cost and adequate reliability was found to be that running from Tilbury, through Delta to Brunswick Point, westwards across Roberts

Bank, and northwest across Georgia Strait to gaps in the submarine ridges east of Valdes Island, landing on the southeast side of Valdes Island.

Valdes Island is crossed north of Mexicana Hill, and Stuart Channel crossed in a northwesterly direction to a landing near Flewett Point on Vancouver Island. The corridor then runs westwards to a junction near the community of Cedar. From the junction, corridors run south over the Malahat to Victoria, and north to Nanaimo and Campbell River.

In general, the corridor consists of a strip of relatively homogenous terrain, up to 5 km or so wide, within which it is possible to locate at least one route. A route, in this context, is defined as a strip of land up to 500 m wide within which it is possible to locate at least one right-of-way alignment.

Route options were identified within the favoured corridor and by comparison of environmental impacts and costs between common endpoints for alternate route segments, the preferred route within the corridor was identified.

The route within the study area is controlled by the factors described in Section 4.3.

2.2 Regulatory Process for Vancouver Island Gas Project

When the project was initiated in 1978, the "Guidelines for Linear Development" were the dominant regulation covering route selection, project approval, and dissemination of project information to the public.

B. C. Hydro prepared its "Corridor and Route Nomination Report" to meet the requirements of Stage 1 of the Linear Guidelines. The field work for this report began in October 1979, the report was written between May 1980 and October 1980 and the report issued in March 1981. Stage 1 of the Linear Guidelines requires only that the favoured corridor be identified. The report went further in that it identified the preferred route within the favoured corridor at a scale of 1:50,000. This was done to give the public a better understanding of the project and its possible effects.

The progress of the project through the "Linear Guidelines" sequence was interrupted by the creation of the B. C. Utilities Commission and the transfer for the supervision of the evolution of this project from the Ministry of Environment to the Ministry of Energy, Mines and Petroleum Resources, apart from the specific legal requirements of OIC 908.

The Minister of Energy, Mines and Petroleum Resources instructed B. C. Hydro by letter on 2nd March, 1981, to construct a natural gas pipeline from Tilbury to a point on Vancouver Island near Cedar, subject to terms and conditions to be decided by the B. C. Utilities Commission. B. C. Hydro submitted its application in June 1981, and has continued to develop project design and route planning to meet this mandate while waiting for the Ministry of Energy, Mines and Petroleum Resources to initiate hearings on the project.

By agreement with the Assessment Branch of the Ministry of Environment, the work done by B. C. Hydro on Roberts Bank for OIC 908 could fulfill the Stage 2 requirements for that section of the preferred route, under the "Guidelines for Linear Development", if these are to continue to apply.

2.3 Response to Corridor and Route Nomination Report

To date no objections have been raised by Government agencies over the choice of the preferred corridor, although no formal integrated response on the choice of corridor has been received from the B. C. Government, as was anticipated under the "Guidelines for Linear Development".

B. C. Hydro has continued to fulfill the spirit and requirements of the "Guidelines" by meeting with regional and local governments (GVRD, Regional District of Nanaimo, Cowichan Valley Regional District, Municipality of Delta, Islands Trust) responsible for the area between Tilbury and Cedar, and with the public in Delta and Cedar, to discuss the project and route selection.

The meetings in Delta, and subsequent review of routing options through Delta, led to several changes to the nominated route. The proposed routing through Delta has incorporated some of the concerns raised by the local farmers and planning staff; the route is described in detail in the "Route Analysis Report" (January, 1983). No comments were received on the route across Roberts Bank.

The Islands Trust confirmed their preference for a route across Valdes Island, rather than one across any other Gulf Island, subject to agreement on construction and routing detail.

With the end points of the Georgia Strait crossing thus broadly acceptable to the regional and municipal authorities involved, B. C. Hydro has proceeded with the analysis and design of the submarine crossings, subject, of course, to the mandatory review as part of the requirements of OIC 908 and any further review by the B. C. Utilities Commission.

3.0 STUDY AREA

3.1 Definition of Study Area

The area involved in the study is defined by the Terms of Reference (see Appendix 2). Its general description is "Roberts Bank from the Steveston North Jetty south to the Roberts Bank Port, bounded on the east by the dykes and on the west by the seaward edge (toe) of the Fraser River delta foreslope". The area is shown in Figure 1.

3.2 Resources and Resource Use of Roberts Bank

The natural resources of the study area are closely associated with its estuarine nature and the variety of marine, intertidal, riverine, and estuarine habitats that exist therein.

The aquatic ecosystem, in particular the fishery resource, is the major feature of the study area. Roberts Bank forms the southern portion of the Fraser delta, and is defined in the north by the Main Arm of the Fraser River, and in the south by Point Roberts. As such, it is on the route of the two major annual migrations of anadromous fish that utilize the Fraser system.

Mature Pacific salmon, steelhead, eulachon, and smelt migrate up the river to spawn in the summer and fall, and the juveniles migrate down the river in the spring and early summer before heading out to the ocean. Other migratory species include cutthroat trout, Dolly Varden char and sturgeon.

Adult salmon are taken by the commercial, sport, and native fishermen as they begin their upstream spawning runs. The management of the Fraser salmon stocks has become an increasingly important issue, and Roberts Bank is one of the more important areas in terms of harvest management.

Juvenile salmonids remain in the study area on the order of weeks to months prior to entering the ocean environment. During this time, the tidal marshes provide a critical rearing habitat for these juveniles.

The foreshore marshes of the study area play an important role in the ecology of the estuary. They greatly enhance estuarine productivity, regulate nutrients, and provide a stable, diverse, and productive habitat for a rich estuarine fauna. Marsh plants are also a major source of food for several species of waterfowl which migrate through, and winter in, the area.

The intertidal banks and the foreslope habitat are important to the annual life cycle of the crab populations. The area along the head of the foreslope supports a significant crab fishery based in Steveston, Ladner and Canoe Pass.

The marshes and intertidal areas provide a major wintering area for geese, ducks, swans, and shorebirds. The resident and migratory birdlife of the area attracts many naturalists year-round, and seasonal goose and duck hunters. Along with commercial and recreational fishing, these are the major public uses of the study area.

The deeper water of Roberts Bank, and the entry to the South Arm of the Fraser are heavily used by marine traffic. This has not been documented in this report as it is broadly irrelevant to pipeline construction across Roberts Bank.

The reader is referred to Volume 2 for a detailed description of the physical features of the study area.

4.0 RELATED STUDIES

4.1 Physical Impact and Construction Methods

Monenco Pipeline Consultants Limited prepared a report on the impacts of pipeline construction on the physical environment of Roberts Bank (Volume 2).

That report describes the existing physical environment of Roberts Bank, the proposed construction method and construction schedule, and the possible variations in methods and schedules, and analyses the impacts on the physical environment.

The physical environment is described in terms of the wind, wave and water current patterns, the hydraulic characteristics of Canoe Pass, and the geotechnical conditions along the proposed route.

The proposed method of construction is described in detail so that the reader may comprehend the various activities involved and the sequence in which they occur.

The potential physical impacts are then analysed, as follows.

At the start of construction a length of trench must be dredged to accommodate the construction train, and the excavated material will have to be dumped. Across the Banks, impacts can be defined as the disturbance through dredging of a large volume of crudely stratified sands and silts, and the mixing and deposition of that material in a different pattern of stratification. During dredging and backfilling, it is anticipated that some of the fines will remain in suspension long enough to be carried out of the trench to be deposited on the Banks. This loss of fines would result in a net deficit of backfill material that would have to be made up by dredging from nearby areas in order to complete backfilling the trench.

The scale and location of these impacts varies with the sequence of construction. The report compares the landwards and seawards sequences and related schedules, and recommends the landward sequence. The landward sequence would require the initial trench to be cut at the head of the foreslope and the final backfill to be done in Canoe Pass.

The construction procedures to lay the pipeline through the marsh and dyke to the shore station, and to connect the Roberts Bank section to the Strait of Georgia section, are described.

4.2 Seismic Effects

Monenco Pipeline Consultants Limited reviewed the effects of seismic loading on the Roberts Bank area, and their analysis is included in their report.

Their analysis establishes that Roberts Bank is an area subject to earthquakes, and that the materials of Roberts Bank are susceptible to liquefaction during major seismic events. It was concluded, however, that liquefaction would only occur during events having an average probability of occurrence of less than once in 160 years, and that even if liquefaction did occur, slumping or flow of material is unlikely anywhere along the pipeline route, and that the pipeline would not likely be damaged even if the liquefaction did occur.

4.3 Aquatic Resources

R. U. Kistritz Consultants prepared a report on the aquatic resources of the study area and assessed the probable impacts of project construction on those resources. Their report is attached as Volume 3.

A detailed inventory of the aquatic resources is provided, including a description of the benthos, marsh environment, invertebrates and fish, and the use of the study area by these organisms. Sediment and water quality characteristics of the study area are also discussed.

An assessment of probable impacts is made, based on the construction method recommended by Monenco, and of the two possible construction sequences and schedules.

The study concludes that dredging should avoid, at all costs, the period of juvenile fish migration through Canoe Pass and inshore areas. The "soft shell" period in the life cycle of the crabs is also seen as a time when dredging should be restrained.

It finds the landwards sequence of construction is preferable provided that an adequate contingency period is planned between completion of construction and the start of juvenile migration in Canoe Pass.

It was determined that concentrations of potentially toxic contaminants in sediments along the pipeline route were within acceptable levels with respect to potential pollution from open-water disposal of dredged material. The prevailing physico-chemical conditions of the sediment water environment and the nature of the proposed dredging method were also considered in the former assessment.

Given the importance of the tidal marsh at Brunswick Point, the need to minimize impact on this habitat was recognized. Therefore, revegetation of the disturbed area is strongly recommended and details are provided for a suitable rehabilitation method.

4.4 Wildlife

Don Blood and Associates prepared a review of the wildlife of Roberts Bank and the impact of project construction and maintenance on the wildlife. The alternate construction sequences and schedules were reviewed. Their report is attached as Volume 4.

It was concluded that direct disturbance impacts would be minimized if construction near the marshes was complete by 1 October. However, wildlife habitat restoration was considered to have higher priority than avoidance of direct disturbance, thus favouring the landward construction sequence when long-term wildlife conservation is considered.

4.5 Recreational and Public Use

Cypress Resource Consultants reviewed the use of the area by people; their report is attached as Volume 5.

The most significant uses are the commercial salmon and crab fisheries, sport fishing, hunting, birdwatching and boating. The deep sea vessels and other marine traffic that use the South Arm of the Fraser were not considered in the study as they would not be affected by construction across Roberts Bank.

The landward sequence of construction would result in some disruption to recreational use at Brunswick Point during the late fall and winter. At this time, Brunswick Point and the surrounding marshes are important areas for duck and goose hunters, and birdwatchers. By blocking Canoe Pass for two months in the fall, the presence of the construction spread would also require commercial fishermen and other boat traffic to use the South Arm to access Georgia Strait.

In all instances these potentially adverse effects were considered less serious than those caused by using a sequence with the potential for major adverse impacts on the juvenile fish stocks, for if construction caused significant mortality among these there may be some adverse affects on certain salmon stocks resulting in potential losses to the fishery.

4.6 Test Engineering Studies

During the period of the study B. C. Hydro applied to the OIC 908 Technical Committee to excavate trial trenches on Roberts Bank to investigate trench side slope stability and rates of infill.

After discussion, a program of two trenches was agreed, and the trenches were excavated by hand-held suction equipment during September, 1980. The work and the results are described in Monenco Pipeline Consultants' report, entitled "Test Trench Study on Roberts Bank", 1980, which is available as a reference.

The tests, while not conclusive, indicated that stable side slopes of between 3:1 and 5:1 can be anticipated in the trench dug for the laybarge.

4.7 Hydraulic Studies

B. C. Hydro commissioned two studies on the hydraulic characteristics of Roberts Bank, available for reference. These are:

- Western Canada Hydraulic Laboratories Ltd.; "Hydraulic and Related Studies on Roberts Bank and Review of Existing Oceanographic, Hydraulic and Geotechnical Information on Sturgeon Bank"; 1980.

- Northwest Hydraulic Consultants Ltd.; "Vancouver Island Gas Pipeline, Preliminary Canoe Pass Scour Study"; 1980.

McElhanney Surveying and Engineering Ltd. was engaged to survey and map the bathymetry of Roberts Bank. Their work has been used in estimating quantities for excavation and project design. Their report, also available for reference, is entitled "Roberts Bank Bathymetry", September 1980.

5.0 PROJECT DESCRIPTION

5.1 General

This section provides a summary description of the project. The reader is referred to Appendix 3 for a detailed description.

5.2 Pipeline Design

The design of a natural gas transmission pipeline is a process of optimizing capital and operating costs of the pipeline and related compression requirements over a design period. In general terms, the design has to strike a balance between using an expensive large diameter pipe and a small compressor station with low operating costs, or a less expensive small diameter pipe and a large compressor station with high operating costs. Ideally the capacity of the system should be capable of being increased incrementally to meet the projected loads. In general, the assumed design period is 20 years; load projections beyond that are based on tenuous assumptions and therefore become highly unreliable.

Several additional factors govern the pipeline design for this particular project. As repair of deepwater submarine pipelines is slow because specialized equipment and personnel must be assembled and deployed, it was decided that the submarine crossings should consist of twin pipelines, each capable of carrying the maximum total firm load projected for the design period. In the event of damage to one line, the second could maintain service to the firm load customers while repairs were made to the first line. The submarine pipelines would be separated by 150 m where they are exposed on the sea floor to reduce the risk of both being damaged by a dragging anchor or sinking of a ship.

Flow capacity of a land pipeline can be increased by looping (paralleling) sections of the line. This is relatively inexpensive as the distance of line that is looped need be no more than that required to achieve an increment in system capacity equal to the anticipated increment in load over a short to medium period, and standard equipment, readily available in B. C., can be used.

For a submarine pipeline, however, the reverse situation holds; the appropriate equipment is not presently stationed in B. C. and is expensive to bring here. A series of short loops and underwater connections to the existing pipes would be difficult, expensive, and unreliable. Any increment in submarine pipeline capacity would have to consist of a parallel pipe for the full length of each crossing. For these reasons, the decision was made to design the initial capacity of the submarine pipelines for the projected 20 year load.

The result of the optimizing process showed that while twin 12"Ø (30 cm) pipes could accomodate the forecast load, twin 16"Ø (40 cm) lines could be constructed at very little extra cost, and provide about 80% more capacity. A final selection of pipe size will be made after consideration of the system capacity by the B. C. Utilities Commission.

The depth of burial of the pipeline across Roberts Bank is an important design consideration, as it determines the scale of trench excavation. The pipeline could be protected from the majority of hazards on the banks, such as a ship's grounding, by about 2 m of fill. However, the critical factor is the migration of Canoe Pass Channel. This channel behaves like any river flowing over an almost flat bed of unconsolidated loose material - it erodes its banks, creating bends, which in turn encourage formation of scour holes.

As there are no artificial or natural restraints to the movement of the channel on Roberts Bank, it may be expected to continue to migrate. Examination of aerial photographs of the channel over the past thirty years, however, has shown only minor shifts in the channel location, but this may change. Surveys of the existing channel found scour holes up to 6 m below top of bank level. The design decision was made that the pipelines be laid at a depth of 7 m from the top of bank level in the inshore portion, and at a depth of 5 m in the offshore portion. This reduced burial depth is justified as the route is on the fringe of the migration area of the channel, and the channel depth reduces as it approaches the foreslope. For the portion in Canoe Pass Channel, the top of the pipelines would be 7 m below local bank level; this would be approximately 3-5 m below the channel bed.

The pipelines would have a corrosion coating of coal tar enamel applied to their exterior, covered with a layer of reinforced concrete. Across the Banks, this would give the completed pipe an overall specific gravity of 1.97. This is the same as that of the soil/water mix that would occur if the unconsolidated material on the banks were to liquefy in an earthquake, and would, therefore, prevent the pipeline from floating to the surface.

Where the pipelines are not buried on the foreslope, the concrete coating thickness would be reduced to give an overall specific gravity sufficient for stability in the ocean currents. To further reduce the risk of damage, the pipelines would be buried with 5 m of cover on the foreslope to the -23 Geodetic datum contour. Where the pipelines lie on the surface on the foreslope, they would be separated by 150 m to reduce risk of damage to both lines by a ship sinking or from a dragging anchor. The pipelines would be protected from corrosion by cathodic protection techniques.

5.3 Pipeline Route

The twin pipelines would be laid across Roberts Bank in a common trench except at the head of the foreslope, where they would be separate for the descent of the foreslope. The pipeline route is shown in relation to major geographic features in Figure 1, and in relation to UTM grid in Figure 2.

The factors affecting route selection were the following:

- The location of the descent of the foreslope was selected as that area having the gentlest slope between the submarine canyons near the mouth of the South Arm and the active area of migration of Canoe Pass Channel to the south.

- The route seawards from Brunswick Point should be such as to minimize the disruption of the marsh at Brunswick Point, and avoid any disruption of the Westham Island marshes.

- The route should minimize the area of disturbance on Roberts Bank; therefore the shortest possible route that could be achieved, and yet be consistent with the previous factors, was chosen.

A right-of-way of 100 m wide is required from Brunswick Point to the point of pipeline divergence near the foreslope where the right-of-way would start a tapered transition to a maximum width of 300 m, where the pipelines are 150 m apart. This pipeline spacing and right-of-way width would continue across the Strait of Georgia to the shore approach on Valdes Island.

Given the weather conditions on Roberts Bank and the nature of construction, it is anticipated that the centreline of the two pipes may drift a few metres from the theoretical centreline of the route. This would not result in any increase in the right-of-way width. Pipeline location would be controlled by survey readings taken from beacons mounted on the shore and on the dolphins marking the Canoe Pass Channel, already tied into the shore beacons by survey.

5.4 Brunswick Point Shore Station

Early studies had favoured a shore station location on Westham Island. This was discarded largely because of the environmental impact on the foreshore marshes resulting from trench excavation through the marsh. In addition, Canoe Pass still would have had to be crossed, and farming activities on Westham Island disrupted.

Brunswick Point is the most western point of the mainland portion of Delta and was a logical terminus for the submarine crossing. It had several other advantages, namely:

- Entry can be made to Canoe Pass with the disruption of only a total of 2.4 ha of marsh, based on 120 m wide working area, of which 0.85 ha would be excavated for the pipeline trench.

- The site location is favourable in that it allows a direct shore pull from the laybarge in Canoe Pass to the shore station, and would result in a right angle cut through the dyke, thereby minimizing the area of dyke that would be breached, and the length of time the dyke would be open. The breached dyke would be protected by a cofferdam.

- A favourable site exists for the shore station on land not presently used for agriculture.

In view of the known ecological importance of the tidal marsh, the use of other landing sites on the south side of Canoe Pass was reviewed. There are only about three sites between Brunswick Point and the Westham Island bridge where it is feasible to bring twin pipelines out of Canoe Pass, through the dyke, and to a shore station within 100 m of the dyke without intruding on developed property. They all have similar disadvantages, namely:

- The curve of Canoe Pass and the requirement of a straight line of pull from the laybarge to get the pipelines ashore force a crossing of the dyke at an acute angle. This in turn requires a longer length of dyke to be breached and a larger coffer dam to protect the breach.

- The cofferdam would have to be constructed in Canoe Pass or else across the public road just inside the dyke.

- Depending on the exact location of the dyke crossing, the public road may have to be closed for up to two months while the shore tie-in was made.

- The shore station would have to be placed on agricultural land.

- Canoe Pass would be blocked for a longer time, and there would be a reduction in the contingency period left in the landwards sequence to ensure completion of dredging prior to the start of migration of juvenile fish in March.

- The dredging of the pipe trench upstream from Brunswick Point in Canoe Pass might affect the stability of the dykes on either side.

- There would be an increase in cost directly proportional to the extra time for which the laybarge is in use. Construction from the barge is much more expensive than construction on land because of the difference in mobilization and operating costs of the equipment involved.

For these reasons a landing at Brunswick Point is preferred. It is recognized that the disruption of the marsh is a potentially serious impact and it is B. C. Hydro's intention to offset this by an effective program of revegetation of the disturbed area.

5.5 Construction Method and Sequence

The proposed construction method and sequence are fully described in Volume 2. For the convenience of the reader, a summary of the description follows.

To achieve the necessary depth of burial, the pipes must be laid in an excavated trench about 8 m deep below the level of the Banks. As it would be impossible to keep any significant length of trench open across the Banks to this depth, the technique favoured is the use of a "bathtub", wherein only a short length of trench is kept open to allow placement of the pipelines while the construction train moves across the Banks.

The first unit in the train is a floating suction dredge which would start by cutting the trenches for the separated pipes at the head of the foreslope and then move landwards cutting one trench along the pipeline route. The dredge pumps the excavated material through a flexible pipe system to the third unit in the train, a backfill unit from which the deposition of the dredgeate is controlled. Between the dredge and the backfill unit floats the shallow water laybarge. This would consist of a modified scow on which pipe lengths are stored, welded to the string, joints X-rayed and coated, and slid into the trench as the laybarge moves forward. The laybarge is winched forward by moving the anchors placed on the banks.

The sequence of operations is shown graphically in Figure 4; a short account follows: At the start of operations at the head of the foreslope, the dredge would cut the separate trenches with the initial dredgeate being dumped on the foreslope or removed by barges. As each trench was prepared, the laybarge would be stationed at the foreslope crest. The pipe lengths would be welded into a string, and pulled into the trench. The capped ends would be left lying on the lower foreslope to be picked up later by the deepwater laybarge. Once the two strings were in place the dredge would start to cut the main trench, and the dredgeate would be used to fill the two separate trenches. Once the excavated trench was long enough to accommodate the dredge, laybarge, and backfill unit in sequence (minimum length of 400 m), the construction train would move steadily landwards with the three vessels floating in a "bathtub" when the Banks are exposed at low tide. Two pipelines would be laid simultaneously and the dredgeate deposited directly in the trench.

The rate of advance would be controlled by dredging capacity as 175-350 m^3 of soil have to be moved per metre of advance. The dredge and backfill unit would operate therefore on a 3 shift, 24 hour day, 7 days a week, basis, while the laybarge crews would work a single shift, 7 days a week.

The dredging would be undertaken as a series of cuts about 2.5-3.0 m deep. It is anticipated that the exposed faces would soon slump to an angle of about 5:1. (See Figure 3.) For an initial excavated depth of 8 m, the maximum width of the trench is expected to be about 75 - 90 m, depending on the characteristics of the soil being excavated in a particular section.

It is anticipated that a percentage of the fine material would be suspended in the water column during dredging and backfilling, and carried from the trench. The accumulated loss would result in the bathtub becoming longer as the train advances, and may require some additional backfill material to be dumped into the trench. The predicted "Excavation and Backfill Material Balance" is shown in Figure 5. When the dredge reaches the marsh at Brunswick Point, it would stop excavating the trench and move downstream to sand banks to obtain the material necessary to fill the last section of trench.

When the laybarge has advanced as close to the dyke at Brunswick Point as it is prudent to go, the ends of the laid pipes would be capped and lowered into the trench. The laybarge would then rotate 180° and be used as a static welding platform on which two strings of pipe would be assembled and pulled into a trench excavated through the marsh to the toe of the dyke. The pipelines would be laid through the dyke by a small land-based pipeline spread to tie in with the land pipeline approximately 150 m inshore of the dyke.

Meanwhile, the laybarge would move offshore to lay the pipelines to where they would be tied-in with the pipelines laid inshore from the foreslope. Due to water depth and other considerations, the ends of the pipelines at the foreslope would be assembled using a similar "pull" technique from the laybarge held in a static position. The end of each pipe would be capped and left unburied so that each may be picked up by the deepwater laybarge to make the final tie-in with the pipelines across Georgia Strait.

The laybarge would require delivery of pipe and materials. This would be achieved using shallow draft barges and tugs, or landing craft, that would cross the banks into the "bathtub" at high tide. Crews would be transported by workboat, hovercraft or helicopter, depending on weather and tide conditions and laybarge location. The use of hovercraft and helicopters would be kept to the minimum to reduce disturbance of wintering waterfowl. The base for workboat operations would probably be in Canoe Pass.

Construction through the marsh at Brunswick Point is shown in Figure 6. The trench excavated from Canoe Pass towards the dyke would taper down to 30 m wide and 4 m deep at which point the cutter suction dredge would be removed and the excavation completed using land based equipment such as draglines, clamshells, and excavators. As this section of the work would be through the tidal marsh, it would be preceded by removal and storage of enough marsh vegetation to permit effective restoration of the marsh following backfill of the trench. The proposed restoration is described in Section 8.7.

The construction through the dyke would be done as shown in Figure 7, using a cofferdam on the seaward side of the dyke to protect the breach in the dyke. The seaward side is preferred as it would have already been disturbed during laying of the marine pipeline, and would prevent contamination of agricultural land inside the dyke due to seawater intrusion. Construction of a cofferdam on the landward side of the dyke would also require rerouting of existing drainage ditches around the cofferdam.

Due to the considerable difficulty of locating and repairing a leak in the buried pipelines, quality control regarding the materials and welding techniques would be rigorous. Each weld would be x-rayed, and any defects cut out and replaced. Prior to connection to the land pipeline, the completed pipelines across Roberts Bank would be hydrostatically tested. Water would be pumped into the pipe at the seaward end and a test pressure of 1.25 times operating pressure maintained for 24 hours. On successful completion of the test the water would be discharged at the seawards end, moved by a pig driven by compressed air introduced at the land end. The discharge water would contain rust and some biodegradable organic corrosion inhibitor.

Should a leak occur, it would require detection of the leak through use of dye or air, excavation to expose the pipeline, and execution of the repair. Excavation would be the greatest problem. Where a dredge can be floated in at high tide a 50 m x 50 m hole would be necessary and possibly up to 200 m long if the pipe had to be cut, raised and welded above water. If a dredge cannot be floated in at high tide, an access trench would have to be excavated to the site.

5.6 Construction Schedule

The proposed schedule is shown in Figure 8. It is based on the landwards construction sequence described in Section 5.5. The schedule is set by the requirement to avoid dredging at the mouth of Canoe Pass during the seawards migration of juvenile salmon in the Fraser River system, and to take advantage of the marsh dormancy period.

Work would start at the head of the foreslope to take advantage of summer weather conditions for the more difficult part of the work, and so that construction activities would be in the more sheltered area of Canoe Pass during the late fall and winter period.

B. C. Hydro has been advised by its aquatic consultant that the earliest probable start of juvenile salmon migration in Canoe Pass is 1 March in any year. It is considered imprudent to schedule dredging up to that date so, after some deliberation, a 60 day contingency period is proposed between 1 March and the scheduled completion of dredging to allow for serious mechanical failures, labour strikes, or other unpredictable delays. The completion of dredging is therefore scheduled for 31 December.

Given this desired completion date for dredging at the Canoe Pass end, and allowing for some downtime due to weather and mechanical conditions, it was calculated that dredging on the foreslope would have to begin no later than June 15th. This schedule is considered realistic in that it assumes use of a 26" dredge, that is, and would be, readily available in B. C. waters. If a larger dredge were proposed by a contractor the schedule could be shortened but B. C. Hydro is reluctant to specify a dredge of such a capacity whose availability on the B. C. coast is uncertain.

The significant environmental aspects of the schedule, which are discussed in Section 7, are:

1. Dredging would start in mid-June on the foreslope, and may overlap with the presence of "soft shell" crabs in that area.

2. Dredge and laybarge would be in the channel of Canoe Pass from mid-October to mid-November, and may interfere with a late commercial fishing season.

3. Activity at Canoe Pass and Brunswick Point from mid-October to the end of January may disturb wintering waterfowl and interfere with hunting.

4. Construction on the exposed, outer portion of Roberts Bank would be at that time of year when the most favourable weather conditions occur, thus reducing the risk of accidents to crew and equipment.

6.0 ALTERNATES CONSIDERED

6.1 Construction Techniques

Four construction techniques, other than that selected, were reviewed, and rejected.

The "trench and pull" technique would require a trench to be cut and kept open right across the banks for the duration of pipe pulling as the pipeline is pulled into it from a static production unit located at either end and then sunk to its final position and buried. This was not considered feasible because it was believed to be extremely difficult to maintain the necessary trench depth while the pipeline was pulled into it.

Deep ploughing techniques have been used to bury submarine cables. A massive plough is pulled along by cable to open a furrow, the cable is slipped in behind the mouldboard and the furrow is closed by a rake. This technique could not be applied as it would not achieve the desired depth of burial.

Jetting techniques have been used for burying cables and pipes to shallow depths in granular soils. In this technique, the pipe is laid across the surface and the jetting saddle, which straddles the pipe, is pulled along behind the laybarge. High pressure water jets on the saddle are directed below the pipe, and as the saddle is pulled forward the granular soil beneath the pipe liquefies, and the pipe sinks. This technique has never achieved the burial depths necessary for this project.

A modification of the "bathtub" technique was also reviewed. Instead of a laybarge it might be possible to use a reelbarge. In this technique continuous lengths of pipe mounted on reels could be brought into the "bathtub" and uncoiled and straightened without welding.

This technique is meant to increase laying speed, but in the "bathtub" method the rate of progress is controlled by the dredging process, and the expense of the reel refinement is not warranted as there are no obvious benefits. Furthermore, the maximum pipe size proposed, 16"Ø, is probably beyond the limit for the reel technique.

Use of land based equipment to lay the pipe on the banks in the standard manner is not possible due to the short working period available in the tidal cycle, the soft nature of the soils, and the required depth of burial.

6.2 Route Location

Three routes were reviewed, all leading to the common point of descent at the head of the foreslope. These are shown in Figure 10 as Routes A, B and C. In addition, a route from Westham Island to the foreslope was considered at an earlier stage, but was rejected because of its impact on the Westham Island tidal marshes and drainage channels, the crossing of Canoe Pass between Westham Island and the Mainland, and cost.

Route A enters Canoe Pass channel at Brunswick Point and follows the channel for about 5 km before striking west to the foreslope.

Route B, the preferred route, follows the same alignment as Route A, but leaves Canoe Pass channel at a favourable bend after 2 km and continues in a straight line to the foreslope. This route was preferred over Route A, as it reduces the period of construction in Canoe Pass Channel, uses a more favourable exit point from the channel, and keeps the pipeline further away from the immediate possibility of scour in Canoe Pass Channel.

Route C, the southernmost route, leaves the mainland southeast of Brunswick Point, and turns northwesterly to maintain the required 150 m distance from the buried electrical cables. This route would, therefore, cross the outer portion of the Brunswick Point marshes. It was rejected in favour of Route B due to the greater potential impact on the marsh, the greater difficulty of marsh restoration in this dynamic and highly sensitive portion of the marsh, and extra length and cost.

6.3 Construction Sequence

Two possible construction sequences and related schedules emerged. The "landwards" sequence has already been discussed in Section 5.6. The other is the "seawards" sequence, shown in Figure 9.

In the seawards sequence, dredging would start in Canoe Pass as soon as the juvenile fish migration was safely over (considered to be 1 July). Construction would proceed seawards, reaching the outer banks in October, with completion of all work at the head of the foreslope in November and December.

The seawards sequence has several disadvantages as it would require the most difficult work to be done under the most arduous weather and sea conditions. The danger to men and equipment, and environmental hazard due to accidental spills, would increase; similarly, higher costs are anticipated due to greater downtime as a result of poor weather. Pipe testing and tie-in would still require activity at Brunswick Point in January, but not through the main part of the hunting season.

7.0 ASSESSMENT OF IMPACTS

7.1 Introduction

The assessment of potential impacts resulting from the construction and operation of a natural gas pipeline across Roberts Bank is divided into four broad categories, namely: impacts on the physical environment, aquatic environment, wildlife, and public use.

Prior to discussing the nature and extent of these impacts, it is necessary to identify several basic assumptions that underlie the impact assessment.

First of all, it was recognized that only a limited number of feasible opportunities exist for avoiding or minimizing potential impacts prior to construction, and to a large extent, these opportunities have been incorporated into the project design. These opportunities can broadly be defined as 1) route location, 2) selection of construction methods, and 3) variation of construction schedule.

Route Location: The location of the route across Roberts Bank was largely determined by the path chosen for descent of the delta foreslope, the crossing of the dyke in relation to the Brunswick Point marshes, migration of Canoe Pass, and the presence of the buried electrical cables south of Brunswick Point. Three route alternatives were examined, as discussed in Section 6. The conclusion reached was in favour of the route that offered the best combination of technical feasibility and environmental acceptability. Thus, other than for minor shifts in the location of the proposed route that would result in little significant difference to potential impact levels, the proposed route was adopted by the consultants, and was used as the basis of the impact assessment.

Construction Methods: In 1978, Monenco Pipeline Consultants reviewed various pipeline installation and burial techniques that might be suitable for Roberts Bank. As the depth of burial required for crossing Roberts Bank was 7 metres, it was concluded that the only feasible, efficient method of burying the pipe was by dredging and backfilling. The comparison of these various methods and equipment is discussed more fully in Section 6. For the purpose of assessing impacts, the method of installation that was adopted is one that utilizes a dredge, laybarge and backfill pontoon, and has been referred to in this report as the "bathtub" method of construction. This method was used for the basis of impact assessment.

Construction Sequences and Schedules: Beyond that which has already been incorporated into the project design, neither the location of the route across Roberts Bank, nor the construction method offered further scope for avoiding or mitigating potentially adverse impacts. Consequently, the scheduling of construction activity, particularly the dredging operation, evolved as the key element that offered sufficient flexibility to be considered as a means for impact mitigation.

Two construction sequences were developed: one that would start at Brunswick Point and move offshore to the crest of the foreslope (seawards sequence), and the other that would start at the foreslope and proceed inshore to Brunswick Point (landwards sequence). The landwards sequence is proposed and is described in Section 5. The seawards sequence, considered less favourable, is described in Section 6. The underlying assumptions concerning weather downtime, differences in backfill deficits, and so forth are given in each description.

The most important factor in determining the dredging window for both construction sequences was the timing of the downstream migration of juvenile salmon. The federal Department of Fisheries and Oceans (DFO) has issued guidelines for dredging in the Fraser River, wherein it is suggested that dredging activity not be permitted after 28 February, and not start again until 1 July. It was further recognized that the dredging window imposed for the expansion of the Roberts Bank coal port was between 1 September and 28 February. It was concluded, therefore, that dredging in Canoe Pass, where fish are generally confined to the narrow channel, would not be permitted after 28 February, hence this date became a determining factor in the construction schedules.

The importance of the Fraser River salmon fishery was recognized at the outset of the study and, as a result, the focus of mitigation efforts was heavily weighted towards this resource. The fishery is important both commercially and recreationally, and has been the object of concentrated effort on the part of fisheries management to conserve and enhance existing stocks. In addition, there has been considerable concern in more recent years about the state of health of the Fraser estuary, with the result that considerable effort and study has been aimed at improving the vitality of the estuary. For these reasons, it was assumed that potential impacts on the salmon resource would have more serious implications than potential impacts on other resources (e.g. crabs or waterfowl) or any temporary disruption of the public's use of Roberts Bank during the construction period.

Having adopted the end of February as a real constraint to dredging in Canoe Pass, the schedules for landwards and seawards sequences were developed.

The landwards sequence would start on the foreslope in mid-June, and would complete dredging and backfilling the shore approach trench by about the end of December. This sequence incorporates a 60 day contingency period to allow for any unforeseeable events that could seriously delay the operation, thus risking completion of the dredging work by the end of February.

The seawards sequence would start dredging at Brunswick Point at the beginning of July, and would be completed on the foreslope by the end of January. The seawards sequence does not incorporate a contingency allowance for unforeseeable downtime as it was considered that dredging restrictions for the Fraser River were not entirely appropriate farther offshore where fish entrainment is not as serious a problem as within the confines of Canoe Pass and marsh channels.

Should unforeseen events delay the completion of dredging for the seawards sequence, there would still be a considerable length of time between the expected completion date at the end of February and the time at which the softshell crab closure is usually imposed on the foreslope, usually by mid-May.

The schedules for the landwards and seawards construction sequences formed the basis for comparison in the overall impact assessment. For each of the four categories previously identified, both temporary and permanent impacts were identified, and their severity compared in terms of the alternate schedules. In addition, the optimum construction window was identified for each impact category to gain an appreciation of the base level of potential impact that would theoretically be achievable, if no other constraints existed. The following paragraphs summarize, in comparative terms, potential impacts on the physical and aquatic environments, wildlife, and public use.

7.2 Impacts On The Physical Environment

7.2.1 Introduction

In general, impacts on the physical environment of Roberts Bank would be temporary, and would, for the most part, be limited to the actual construction period of 199 days for the landwards sequence, and 214 days for the seawards sequence. This does not include the 60 day contingency period for the landwards sequence, or the 130 days required for mobilization and demobilization. Physical impacts would occur as a direct result of dredging and backfilling operations, although it is intended to keep these potential impacts to a minimum through careful project design, close supervision during construction, and adequate restoration of the affected area once the pipeline has been installed. The potential physical impacts identified by Monenco include possible changes in channel and bank morphology in Canoe Pass, water quality, and substrate composition.

7.2.2 Effects on Channel and Bank Morphology

Foreshore Marsh: The area of foreshore marsh that would be excavated for the pipeline trench is approximately 0.85 ha, and the total working area that would be disturbed by construction activity, such as stockpiling material adjacent to the trench, is approximately 2.4 ha, based on a working area width of 120 m.

To the extent possible, the trench through the foreshore marsh would be restored to its original profile, to achieve a similar sequence in elevation, and hence in vegetative communities, to that which presently exists.

The restoration procedures for the marsh are described in detail in Section 8.5, and will not be duplicated here.

Canoe Pass Channel: Where the pipe enters and exits Canoe Pass Channel, the channel banks would be trenched and backfilled. On the east side of the channel adjacent to the marsh, the trench would remain open for the duration of construction; this is not considered to be a problem as the bank, at this location, is accreting, and is therefore expected to remain fairly stable during the time it remains open to the main flow of the channel. Once the pipe is installed, the trench would be backfilled, and the bank restored to its former profile. If the landwards sequence is adopted, there would be a deficit of material to complete backfilling the trench when the dredge reached the limits of its easterly travel in Canoe Pass, requiring that material be dredged from sandbanks downstream to restore the bed of the channel.

Within the channel itself, the pipes would be buried approximately 3-5 m below the channel bed, and the installation of the pipes is not expected to alter the channel morphology.

On the west bank of the channel, there is a greater risk of bank erosion as the trench breaks through on the outside of a bend. It is therefore proposed that, in the landwards sequence, the trench, where it breaks through the bank, be sealed with two coarse sand plugs to prevent exposure of the unconsolidated backfill to erosive flows in Canoe Pass when the 'bathtub' is open to Canoe Pass and after it has passed into Canoe Pass. For the seawards sequence a single plug would suffice. The bank would be allowed to reform under natural conditions after placement of the plug; this is expected to occur following the next spring freshet.

Intertidal Sandflats: Across the intertidal flats, the maximum width of the pipeline trench would be 90 m; the total width of the disturbed area would be approximately 200 m, within which the anchors would be placed, and auxilliary equipment would sit at low tide.

The trench would be backfilled, leaving a low hump over the trench that would eventually be flattened out by tidal currents. This would act as a precaution against leaving any depression in the trench that could act to channelize tidal flows, possibly resulting in scour. It is considered probable that the currents across the intertidal flats would flatten out the excess backfill in a few days, given the nature of the soil.

Foreslope: The trenches on the crest of the foreslope would be backfilled to the -13 m Geodetic datum contour, where coarse sand plugs would be placed in the trenches to prevent loss of backfill material down the foreslope. The trenches downslope of the plugs would be allowed to backfill naturally, and it is believed that this would occur rapidly due to the foreslope's exposure to wave action and the silty, unconsolidated nature of the surrounding material.

7.2.3 Sediment Dispersal

During dredging and backfilling of the trench, some fine sediments would be dispersed in the water column and when the tide level covers the bathtub, much of this suspended material would be swept out of the bathtub by the currents.

Factors controlling the characteristics of the discharge plume are the particle size distribution, particle settling rates, salinity, discharge rate, water depth, wind and current velocities, and the configuration of the discharge nozzle.

The nature and persistence of discharge plumes are controlled largely by the settling rate of suspended material in the water column. Settling rates are largely governed by the size of particles in suspension; finer particles remain in suspension longer than larger size particles.

Sediment samples collected along the proposed pipeline route across Roberts Bank show that the majority of sediment is classified as silty sand. Deposits on the delta foreslope are generally finer than those on the intertidal flats. Surface sediments in the foreshore marsh are much finer than elsewhere along the route, and are composed primarily of silts and fine sands.

It was estimated that the average percentage of fines (i.e. particles 74 micron Ø) contained in the sediments is 10%, although small lenses of 10-25% silt were sampled. Low concentrations of silt and clay will settle very slowly, creating large, persistent turbidity plumes. Where concentrations of fines, particularly clays, are high, however, the particles tend to coalesce, forming flocs that generally settle more rapidly.

The degree of flocculation is found to increase with a corresponding increase in salinity up to a concentration of 10 g/l. Between concentrations of 10-35 g/l, the degree of flocculation remains fairly constant. Salinity in the water across Roberts Bank is well within the range to promote flocculation; however, as the majority of the sediments are micaceous silts and sands, and contain less than 3 per cent clays, it is unlikely that any significant amount of flocculation would occur.

A "worst case" estimate of the discharge plume was prepared by Monenco, based on a method proposed by the U. S. Corp of Engineers Waterways Experiment Station. The assumptions used in this estimate are outlined in Volume 2.

The results showed that during the two hour period preceding or following high tide, the plume would extend for approximately 4.7 km in the direction of the tidal current, but would have reached average background turbidity levels (25 g/l) approximately 1.7 km from the discharge nozzle. The plume would be reach a maximum width of roughly 1 km.

As the pipeline route parallels the direction of the tidal currents for much of its length, suspended material would tend to settle out in the direction of the route; into the "bathtub" during one tidal cycle and outside, or away from the bathtub during the other cycle, depending on the construction sequence adopted. For approximately half an hour at the change of tide, the current would flow across the trench, and a small plume would occur to the south of the trench.

This estimate of the characteristics of the discharge plume, and the expected turbidity levels, is based on anticipated conditions, such as average current speed and direction, water depth etc. Unpredictable factors, such as weather conditions that would undoubtedly have a significant effect on sediment dispersal, were not considered due to the difficulty of predicting these effects. As a general observation, though, it is expected that on the foreslope, sediments would be dispersed over a larger area than on the intertidal flats or in Canoe Pass due to the higher percentage of silts contained in the sediments, the greater water depth, and the greater exposure to more severe winds and waves that would aid dispersal of the fines.

Dredgeate Losses: In order to bury the pipes and return the excavated trench to its original level, dredged material would be discharged into the pipe trench to a level just above the surrounding bank (0.5 m above). During the backfill operation, there would be inevitable loss of material, particularly of the finer particles. These losses, however, can be kept to a minimum by submerging the discharge nozzle below the surrounding bank level of the "bathtub", thereby limiting losses to 5-10 per cent of the total volume dredged, or approximately 130,000-210,000 m^3.

Across the intertidal sandflats, loss of material is largely influenced by the tidal cycles. Assuming an average bank level of -2.0 m GSC, it was estimated that at very low tides which occur for about 5% of the time, all of the discharge material would be contained within the "bathtub", and no losses would occur.

As the tide rose, the nozzle would be kept slightly below the adjacent bank level, until such time as when the nozzle would have to be raised above the bank level in order to complete backfilling of the trench. The raised position would be maintained for about 3-4 hours per day, at high tide, and would therefore incur the greatest losses of dredgeate. At this time, losses are estimated to range between 10-25% of total volume dredged, depending on the silt content in the material. The total loss during construction across the intertidal flats would be roughly 85,000-120,000 m^3.

Within Canoe Pass Channel, the discharge nozzle would be submerged at all times, and the discharge plume would be continually fluctuating with the ebb and flood tidal currents in the channel. It is envisaged that the loss of dredgeate would range between 5-10% of the total backfill volume, and would eventually be washed downstream in Canoe Pass. This represents between 50-100% of the average sediment load within Canoe Pass, assuming that 7% of the sediment load of the Fraser River flows through Canoe Pass. The increase in sediment load in the channel would only be temporary, for about two months.

The cutter suction dredge would continue to operate to within approximately 100 m of the dyke. If the landwards sequence is adopted, the dredged material would be used to backfill the trench in Canoe Pass, and would therefore be subject to the same percentage loss as for Canoe Pass.

The shore approach trench inshore of the 100 m chainage mark would be excavated using a clamshell dredge or a similar type of land-based equipment. The excavated material would be stockpiled adjacent to the trench for approximately one month, and would be subject to a certain amount of erosion due to wave action at high tide. Some of the finer material would be washed into Canoe Pass, but this amount represents a relatively insignificant fraction of the total losses.

The following table summarizes the estimated loss of sediment associated with the various phases of construction.

Summary of Dredgeate Losses

Location	Average Loss (% of Total Volume Dredged)	Quantity ('000 m^3)
Intertidal Flats	5 - 7	85 120
Canoe Pass (including volume dredged by cutter suction dredge inshore of Canoe Pass channel)	5 - 10	45 - 90
Shore Approach Trench	minimal losses	nominal
Total		130 - 210

7.2.4 Effects on Water Chemistry

The assessment of the effects of dredging on water chemistry is based on knowledge of the existing geochemical and water quality conditions along the pipeline route as documented by Kistritz et al. (1981), and on the proposed construction methods as outlined by Monenco (1981).

Two key factors distinguish the dredging operation for the gas pipeline project from most other hydraulic dredging programs; these are: 1) during most of the dredging operation, the dredgeate is redeposited within the "bathtub" to backfill the trench, and 2) dredgeate is deposited to within 0.5 - 1 km of its origin. Both of these technical factors act to localize the effects on water quality.

The existing water quality conditions on Roberts Bank can be summarized as follows:

(a) tides and currents are such that the water mass is relatively well mixed;

(b) natural suspended sediment loads are generally high, particularly during the river freshet;

(c) sediments along the pipeline route do not appear to be contaminated with toxic pollutants;

(d) the shallow water overlying the intertidal sandflats is well oxygenated, moderately buffered, of low to moderate productivity (nutrient levels), and has widely fluctuating salinity and temperature conditions;

(e) there are no existing water pollution problems in the immediate vicinity of the pipeline route.

Dissolved Oxygen Levels: Dredging operations can affect dissolved oxygen levels in that the suspended solids in the discharge plume may impose an oxygen demand on the surrounding water, if they contain unoxidized organic or inorganic material. It is believed that the dredgeate will have a low organic content, except for the material from the marsh.

Dissolved oxygen levels are generally quite high in the Fraser estuary, frequently in excess of 80% saturation. Both temperature and salinity affect dissolved oxygen levels, as warmer temperatures and increased salinity tend to decrease dissolved oxygen concentrations. The following table indicates lowest mean monthly dissolved oxygen levels that have been recorded in the Fraser estuary region in recent years.

Location	Month	Dissolved Oxygen (mg/l)
Woodward Island - riverine conditions	July	9.0
Sand Heads - mixed estuarine	September	7.7
Tsawassen Ferry Terminal - marine	September	7.5

It was concluded, therefore, that water surrounding the discharge plume would tolerate a substantial oxygen demand before levels would be depleted to that considered lethal to salmon (below 4-5 mg/l). This conclusion is expected to apply throughout most tidal conditions when water levels are above local bank level, and there would be sufficient mixing to replenish the supply of oxygen to the water contained in and surrounding the "bathtub".

The worst situation would occur when the bathtub is isolated, when tides are at or below mean low tide. During the spring, the maximum period of isolation may be as long as 3-4 hours per day, during which time there would be a potential consumption of 1.9 mg/l dissolved oxygen, in terms of the total volume of water in the "bathtub". Assuming that the water in the "bathtub" would be relatively well mixed, dissolved oxygen levels are not expected to approach those critical for aquatic organisms, nor would they be low enough to trigger the rapid release of toxic, reduced compounds. The latter case would only tend to occur when dissolved oxygen levels approach zero, giving rise to anoxic conditions.

Release of Toxic Contaminants: The release of substances from dredged material at concentrations that may be lethal for aquatic organisms, or that may become incorporated into the food chain, is a concern commonly associated with hydraulic dredging operations. Organohalogens and certain trace metals are known to adversely interact with the food chain, whereas lethal and sub-lethal effects are often attributed to the release of ammonia and hydrogen sulphide. The release of large amounts of nutrients is primarily an aesthetic problem in terms of the undesirable effects of eutrophication. Concentrations of potential toxic contaminants in sediment sampled along the pipeline route were generally within the range of values cited for sediments in unpolluted locations of the Fraser estuary.

Organohalogens: Fourteen sites were sampled along the pipeline route for organohalogens, and not one contained any detectable levels of DDT. Pentachlorophenol (PCP) was found in some samples, probably due to pollution from numerous potential upstream sources associated with the wood preserving industry. The levels, however, were well below those found in what are considered as contaminated sediments in the estuary. Levels of polychlorinated biphenyls (PCB) were found to fluctuate within an expected range of values reported for various locations in the estuary away from pollution sources, or were undetectable. Chlorinated hydrocarbons will not be released to solution in detectable quantities during dredging activities. They may, however, be taken up by filter-feeding organisms in a particulate phase.

Due to the low or non-detectable levels of organohalogens present along the pipeline route, the relatively low percentage of fines in the dredgate, and the relatively short duration of the turbidity plume, it was concluded that toxic organic contaminants would not have a significant effect on water quality.

Trace Metals: Results of sediment analyses along the pipeline route showed that levels of both mercury and cadmium generally fall below the 0.75 ppm and 0.6 ppm limits established under the Ocean Dumping Control Act (1975). All other trace metal levels reflected the concentrations generally found in natural, unpolluted sediments in the estuary.

Elutriate tests, employed to simulate the release of chemicals from sediments in hydraulic dredging operations, were performed in other studies on both Robert's and Sturgeon Banks, and showed releases of only zinc and iron. The low release of trace metals in dredgeate dumped in the ocean is believed to be due, in part, to the strong adsorption capacity of suspended sediment itself, especially under oxidizing conditions, and in the presence of effective trace metal scavengers such as iron hydroxides.

Nutrients: The potential release of nitrogen and phosphorous from dredged sediments may be significant in the Brunswick Point marsh, where marsh soils contain nutrient levels substantially greater than those found along the route in Canoe Pass or on the intertidal sandflats. Average nitrogen and phosphorous concentrations were found to be four and two times greater, respectively, than concentrations found in all other sediment samples collected at other locations along the route. The effects of increased nutrient concentrations would be most pronounced in the immediate vicinity of the point of discharge, and during those times when the "bathtub" is temporarily, and infrequently, isolated at very low tides.

Ammonia & Sulphides: Dredged sediments that are inclined to release large amounts of nutrients may also have the potential for release of ammonia and hydrogen sulphide, both of which are toxic to aquatic organisms. Although a source of ammonia is potentially available, especially in the marsh soils at the shore approach to Brunswick Point, it seems that the hydraulic and chemical conditions favouring the release of toxic concentrations of ammonia to the water in Canoe Pass would very rarely occur. Most of the sulphur in marsh soils is stored as non-toxic, relatively inert pyrite; furthermore, the small quantity of soluble sulphides present in the marsh soils would oxidize rapidly, rendering them harmless to aquatic organisms. Therefore, for sulphide concentrations in the dredged material to reach toxic levels, concentrations of several hundred ppm would be required. Measured soluble sulphide concentrations in sediment samples were below 3.5 ppm, and the discharged dredgeate would, in any case, be rapidly diluted by the flushing action through Canoe Pass.

7.2.5 Effects on Substrate Composition

The excavation of the trench by hydraulic suction dredge is achieved by loosening the sediments with a rotary cutter head, pumping the material in a slurry through a discharge pipe, and redepositing it in the trench. Such a procedure will inevitably result in the mixing of sediments in the slurry, some loss of fines, and redeposition in a location approximately 500-1,000 m from the point of origin.

As discussed by Monenco (Appendix 3), sediments sampled along the pipeline route were found to be relatively uniform in composition, with two major exceptions: namely; 1) at the foreslope, and 2) in the shore approach through the Brunswick marsh. In both areas, there is a higher proportion of fines present in the sediments.

Over the length of the pipeline route, there will be a loss of fine sediments, averaging between 10-15% of the total volume dredged. As a result, the material that would be pumped back into the trench would tend to be slightly coarser than sediments immediately surrounding the trench. In addition, due to the mixing of sediments in the suction dredge, and the method of redeposition in the trench, there would be a change in the stratification of the backfill material as compared to the adjacent sediments. The significance of these effects in terms of the physical change in the substrate compositon is considered to be negligible. These effects may, however, influence the structure of benthic communities along the pipeline route, as discussed in Section 7.3.

The replacement of surface sediments and the vegetated layer removed from the shore approach trench adjacent to Brunswick Point is, similarly, of concern from a biological rather than physical perspective, and is described in detail in Section 7.3.5.

7.3 Aquatic Environment

7.3.1 Introduction

Potential impacts on the aquatic environment are primarily related to the effects of the dredging operation across Roberts Bank. These effects result from excavation of the pipeline trench, construction activities that extend beyond the width of the trench, but remain within the 200 m wide working area, and the potential introduction of contaminants into the aquatic environment due to the operation of construction equipment, and/or accidental spills.

This section describes the nature and severity of potential impacts in terms of the major biological communities that stand to be affected by pipeline construction activities.

The implications of the landwards and seawards construction sequences are also addressed.

7.3.2 Benthic Communities

The benthic environment along the pipeline route can be broadly divided into four "zones" or habitat types:

1. the marsh/mudflat
2. riverine (Canoe Pass)
3. the intertidal sandflat
4. the subtidal foreslope

Each of these zones has somewhat different benthic characteristics in terms of density of benthos and composition of communities. In general terms, it has been reported that the maximum density of benthic organisms is found in the mudflat adjacent to the marsh. Densities of invertebrates in Canoe Pass were roughly one order of magnitude lower, those on the sandflats about one-half of those in Canoe Pass, with lowest densities found on the outer flats at elevations of less than +1.0 m. Much higher densities were found on the foreslope.

The least diverse community occurred in the mudflat, which is largely dominated by a single species of polychaete. The Canoe Pass community is dominated by two species. The intertidal sandflat, though relatively uniform in sediment composition, covers a large area that is subject to a range of tidal heights and therefore exposures, resulting in a heterogenous distribution of benthic invertebrates.

During excavation of the trench, benthic organisms would become entrained in the dredgeate slurry and deposited in the backfilling process at a depth that would result in mortality. The combination of these two events is forecast to cause virtually total destruction of benthic populations originally within the pipeline trench. The chief concern, is therefore, not with attempts to mitigate mortality caused by dredging, but with the subsequent recovery of benthos along the pipeline route.

The total area of benthic habitat that would be dredged on the intertidal sandflats is estimated to be 41.35 ha. This represents 0.6% of the total intertidal sandflat area of Roberts Bank.

The total loss of benthic biomass is estimated to be in the order of 2,000 kg. This represents less than 1% of the total benthic resources of the intertidal area of Roberts Bank.

The following table provides an estimate of the benthic losses expected along the pipeline route.

ESTIMATED LOSS OF BENTHOS ALONG PIPELINE ROUTE ACROSS ROBERTS BANK

Habitat		Total area to be dredged (m^2)	Mean Benthic Biomass (g/m^2)	Total Benthic Biomass (kg)
Marsh/mudflat		8,500	25.97[3]	220.7
Riverine		164,400	1.1	180.8
Sandflat	inner	322,200	1.7	547.7
	outer	127,800	0.84	107.3
Slope		111,000	11.1	1,232.1
Total		733,900		2,288.6

Construction activities would cause additional disturbance of the benthic environment adjacent to the trench as a result of smothering, trampling, and exposure of benthic organisms by equipment, anchors, stockpiling of dredgeate, and sedimentation from the sediment plume. Of these effects, stockpiling of dredged material is expected to be most harmful to benthic organisms, as burial may result in some mortality, depending on its depth and duration. These effects will be of a temporary nature, and will be largely restricted to the working area on either side of the trench. Within a short period of time, it is expected that the tidal and river currents and wave action would act to restore the affected area to its former profile. For this reason, these secondary activities are considered to have a much less significant impact on the benthic environment than the excavation process itself.

Expected Recovery of Benthic Communities:

The construction of the pipeline is not expected to cause permanent destruction or alienation of benthic habitat. The backfilled trench would provide fresh substrate for colonization; this colonization, coupled with subsequent in situ reproduction will contribute to the re-establishment of a benthic community along the dredged area.

The optimal rate of recovery of benthic communities would be achieved if dredging is completed shortly before the seasonal increase in biological activity. Recovery rates can be further hastened by strong wave and current action which aids in adult dispersal into the dredged area. It was concluded, therefore, that winter dredging would promote the most rapid recovery of benthic communities along the pipeline route. Recovery along the pipeline route is expected to occur within one year following completion of dredging.

The anticipated long-term change in sediment characteristics along the pipeline route (i.e. to coarser sediments due to loss of fines), may result in a "climax" benthic community that differs from that existing prior to construction. This potential long-term effect would be more apparent at depth, rather than at or near the surface, because the surface sediments are expected to regain their former characteristics after the first few storms, and the first freshet period following completion of dredging.

7.3.3 Crabs

Dungeness crabs make seasonal use of Roberts Bank, and will be present along some sections of the pipeline route at three times during their life cycle. Presently, no accurate estimates of population abundance exist, however the migratory patterns of crabs on Roberts Bank are broadly understood, as follows:

(i) adult crabs migrate onto the intertidal sandflats from February to May;
(ii) moulting, or "soft-shell" crabs occur between April and September, and it is at this time that adult crabs are least mobile, and therefore most vulnerable to damage. In the past, "soft-shell" fishery closures have been in effect between mid-May to mid-June; and
(iii) in July and August, adult crabs congregate on the foreslope for reproduction, and stand to be affected by summer dredging in that area.

Juvenile crabs settle on the banks in late August and September, and may remain buried on the intertidal sandflats over the winter.

Potential Impacts

Hydraulic dredging has been found to be very harmful to crabs, particularly when a suction dredge with a rotating cutter head is used. Dredging in sandy substrates was found to be more damaging than in silty material; and survival rates of crabs generally improved as their size decreased.

Crabs that become entrained in the dredging slurry suffer a high rate of mortality. In addition to this direct impact on crab populations, crabs could also suffer from the temporary loss of a food source - the benthic organisms that would be almost entirely destroyed along the pipeline route. On the other hand, dead benthic organisms deposited near the surface of the backfilled trench could provide a feeding "bonanza" for the surviving crab population.

Although crabs are presently on the banks throughout the year, the time during which they are most sensitive to damage is when they are moulting, they then remain relatively immobile, buried in the sand. The moulting period varies from year to year, but is generally of concern between mid-May to mid-June. During the reproductive phase, in July and August, crab populations are relatively dense on the foreslope, and therefore would risk a high rate of mortality since entrainment levels are directly proportional to the population densities. In conclusion, it was considered that dredging activities would be least damaging to crabs between September and April.

7.3.4 Fishery Resources

A review of the fishery resources was undertaken by Kistritz (1981), to document the spatial and temporal distribution of fish on Roberts Bank and in Canoe Pass. Emphasis was placed on those species having economic, recreational, and aesthetic importance, particularly the migratory salmon species that utilize the Fraser estuary.

Migratory fish pass through the estuary twice during their life cycles; first, as juveniles migrating downstream to coastal or oceanic feeding areas; and secondly, as surviving adults when migrating upstream to spawn. The following description of potential impacts is based on information reported by Kistritz, and is primarily concerned with the potential impacts on the salmon species. Impacts associated with other species of fish such as herring, eulachon, and groundfish, were of lesser significance, and therefore were considered less critical in terms of decision making in the construction scheduling.

Temporal Patterns of Fish Use

Some fish will be present along the pipeline route at all times of the year. Juveniles are present in the marsh and in Canoe Pass in the spring, as early as late February to early March, and as late as early July, in some years. Recognizing the potential entrainment of migrating juveniles by dredging operations, the Department of Fisheries and Oceans prepared guidelines for dredging in the Fraser River. Dredging is to be suspended in the river channels between 28 February and the end of May, although this closure may be varied in years of exceptionally early or late migrations. In view of the importance of the marsh habitat for juveniles, as reported by Kistritz, it is particularly critical that no dredging occur in the marsh during this closure period.

Adult migration through the estuary occurs year round, but the dominant period of use is between June and October. The abundance of salmon in the estuary varies considerably from year to year, depending on the strength of the returning runs, and which stocks are present in a given year.

Spatial Patterns of Fish Use

The variations in spatial distribution of fish in the estuary are not as well understood as temporal patterns of fish use, largely because of the difficulty of sampling such a diverse and expansive area as the outer estuary. Several general comments can be made concerning the spatial patterns of fish use, based on existing information summarized by Kistritz.

Of the four habitat "zones" crossed by the pipeline, (marsh/mudflat, riverine, intertidal sandflat, and foreslope), the marsh is the most important habitat for juvenile fish. Its importance as a rearing area, and particularly that of the tidal channel system for fry, has been well documented.

Canoe Pass provides a temporary habitat for migrating fish. During the spring, Canoe Pass provides access to the marshes and from there to the ocean for many juvenile fish, particularly the salmonids. Large numbers of eulachon larvae are found in the plankton in the channel in the spring.

Canoe Pass provides access to spawning grounds for upstream migrating adults during the late summer and fall. During the spawning migration, it is preferable that Canoe Pass remain unobstructed, as many of the returning species, particularly sockeye salmon, have limited energy reserves with which they must complete their upstream migration.

Seine surveys conducted on Roberts and Sturgeon Banks showed that, in general, the intertidal sandflats in proximity to the pipeline route are of lesser importance as fish habitat, in comparison to inner flat areas that appear to receive higher use. Large drainage channels on the flats are major topographical features that seem to attract fish. Topographical depressions that retain water at low tide, be they natural or man-made, provide a refuge for fish.

Potential Impacts

Of all the aquatic resources that could be affected by the construction of the pipeline, it is the fishery resources, particularly the salmon species, that are of primary concern because of their economic, recreational, and ecological importance.

The potential impacts of pipeline construction on the fishery resources fall into three categories:

1. the effects of excavation activity, including the direct impact of dredging and the indirect impacts associated with the temporary presence of the depression formed by the "bathtub";
2. indirect effects of construction activities, resulting from the temporary loss of the benthic food source along the backfilled trench; and

3. indirect effects associated with the sediment plume and increased turbidity within the bathtub resulting in temporary degradation of water quality.

Fish Entrainment: The operation of a hydraulic dredge in the marsh and Canoe Pass in the spring would result in the entrainment and destruction of migrating juvenile salmonids. Due to their poor avoidance capabilities, the number of juveniles entrained in the dredging operation would be proportional to their densities in the path of the dredge. It is apparent from studies done to date that the marsh habitat, particularly the drainage channels in the marsh, and Canoe Pass itself, would be the most sensitive areas for juveniles, as it is in these areas that juveniles tend to be most concentrated. Both residence times and fish densities are expected to be much lower across the intertidal sandflats.

Adults migrating upstream in the late summer and fall should be able to avoid entrainment in the dredge, but their migration runs could be delayed if the presence of the construction train in Canoe Pass acted as a deterrent to further migration. The seriousness of this potential impact is not well understood, as it is not known to what extent returning fish would find other ways of getting up the Fraser River, if deterred in progressing up Canoe Pass.

Monenco has estimated that construction through Canoe Pass would require up to two months. For the landwards sequence, construction in Canoe Pass would occur between mid-October and mid-December; for the seawards sequence, construction would occur between mid-August and the end of September.

August, September, and October is the period during which the sockeye salmon migrate through the lower estuary. Due to the importance of maintaining the Fraser sockeye stocks, primarily for commercial purposes, it was considered appropriate to attempt to minimize potential interference with these runs during construction. In comparing the two sequences, therefore, the landwards sequence appears to be acceptable, as construction in Canoe Pass may only coincide with the latter portion of the run in mid-October; the seawards sequence, in contrast, appears much less favourable as it would involve a possible blockage of Canoe Pass during the most critical months of the sockeye migration.

In addition to the salmon species, several fish species that presently have no commercial importance are known to be present along the pipeline route. In general, those species that live near the bottom, and feed on benthos are most susceptible to entrainment in the dredging process. As mentioned previously, though, fish densities on the sandflats north of Canoe Pass are low compared to other parts of the Fraser Delta.

Another point of some concern is that the "bathtub", being a fairly large topographic depression on the sandflats, would become a temporary, but potentially attractive refugium for fish at low tide. Clearly, if fish collected in the "bathtub", there is a greater potential for damage to them, as more would be caught by the dredge, and as a result of high turbidity levels in the "bathtub" itself.

Temporary Loss of Food Sources

The potential loss of benthic organisms along the pipeline route was discussed in Section 7.3.3. The subsequent reduction of some components of the food-web constitutes an indirect impact on fish populations in the estuary. This potential impact, however, was considered to be a minor one, for the following reasons:

1. the loss of benthos should not amount to more than 1% of the total benthic standing crop of Roberts Bank;
2. benthic invertebrate populations would largely recover within one year of construction;
3. fish are mobile, and can, therefore, move to other, unaffected areas for their food supply; and
4. fish on the sandflats tend to prefer food that consists of larvae and juvenile fish, and motile benthic organisms. As the majority of these prey are unlikely to be seriously affected by dredging, the effect on fish predators would be low.

Effects of Change in Water Quality: As discussed in Section 6.2.3, the dredging and backfilling operations would result in an increase in suspended sediment levels in the turbidity plume and in the "bathtub" itself, which in turn may adversely affect fish. In terms of water quality, though, it was previously concluded that potential changes in water quality would be of a minor and temporary nature, and would not constitute a significant problem for fish in the area surrounding the bathtub. Although levels of suspended sediments in the immediate vicinity of the discharge nozzle are high, estuarine fish are known to tolerate high suspended sediment levels for several weeks without mortality.[1]

7.3.5 Marsh Habitat

Brunswick Marsh represents approximately 7% or 164 ha of the total area of foreshore marsh in the Fraser Delta. Typical plant species found in the brackish marsh are bulrushes, sedge, and cattails. Saltmarsh, typified by plants such as saltgrass and saltwort, is found only at the southeast end of the marsh.

There are two major components to the marsh community, namely:

1. the above-ground annual growth of vegetative and reproductive shoots; and
2. the perennial below-ground organs which store the energy and nutrient reserves of the plant.

Although the below-ground roots and rhizomes are essential for the continued growth of the plants, and are an important source of food for snow geese and swans, it is the above-ground vegetation that provides critical habitat for a variety of fish, wildlife and other secondary organisms. The potential impact of pipeline construction through the marsh, and the rate and degree of recovery of the marsh are, therefore, of some concern.

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[1] Peddicord and McFarland. 1978.

Pipeline Route

The pipeline route would cross the northeast section of the Brunswick Marsh, as shown in Figure 11. Construction through the marsh would require excavating a trench by land and marine based equipment, backfilling the trench, and replanting the marsh vegetation to conform to its original state. Approximately 8,500 m^2 of marsh would be stripped off in order to construct the trench. This material would be stockpiled adjacent to the trench for about 45 days.

In addition to the area of marsh that would be removed during trench excavation, there would be an additional 15,500 m^2 of marsh adjacent to the trench that would be temporarily disturbed, assuming a working area width of 120 m. Together, the total area of marsh that would be disturbed through excavation, stockpiling of material, and movement and storage of equipment is estimated at 24,000 m^2, or roughly 2.4 ha.

In a regional context, this area of disturbance represents approximately 1.5% of the Brunswick Marsh, and 0.34% of the Roberts Bank foreshore marsh. Moreover, it constitutes a temporary disturbance, as the marsh is expected to begin recovery after one growing season, given that restoration procedures are successfully carried out.

Potential Impacts

Trench Excavation: Excavation of the shore approach trench would entail the complete removal of marsh vegetation. The level of impact can therefore, only be assessed in terms of the rate and degree of success in restoration of the marsh. Several factors appear to favour successful restoration along the trench; namely, that the area to be excavated is quite small, disturbance would be for a short period, and the presence of marsh on either side of the trench would act as a protective buffer and as a source for plant recolonization. The success of restoration is dependent on the stability of the substrate, and the extent to which the original topography and drainage patterns can be re-established. Several possible techniques for restoring the marsh were reviewed, and are described in Section 8.7.

Trampling and Smothering: As previously mentioned, the working area adjacent to the trench will be subject to trampling and smothering as a result of movement of equipment, and stockpiling of dredged material and vegetation plugs. Possible damage to the roots and rhizomes could occur where the operation of heavy equipment penetrates the surface layer of vegetation. The smothering of plants by stockpiled material would be temporary; however, there is a possibility that some of the dredged sediment will become dispersed due to wave action, and be redeposited elsewhere in the marsh. If these deposits do not exceed depths of 20-25 cm above the original elevation, plant growth should not be significantly impeded.

Potential Pollutants: The operation of equipment may result in the introduction of petroleum products into the marsh soils. As marsh soils tend to readily adsorb petroleum hydrocarbons, and store them for long periods of time, it is essential that the utmost care is taken to avoid even minor spills or leaks from equipment. Hydro will comply with the existing regulations concerning refuelling operations and any other reasonable precautionary measures that may be required by the Ministry of Environment.

Impact Mitigation Measures

The potential impacts on the marsh environment can be minimized through careful construction and restoration procedures, and through scheduling of construction activities.

Scheduling: Based on what is currently known of the life history of plants in the Fraser estuary marshes, it is believed that impacts on the marsh vegetation would be least severe if construction occurred between November and March. During this period, the above-ground shoots would have receded, and the roots and rhizomes would have replenished their energy reserves in preparation for the following year's growing season. For this reason, the landwards sequence is preferred, as excavation through the marsh would start in November, and backfilling would be completed by the end of December. This means that the stripped material would be stockpiled for approximately two months, whereupon replanting could begin in January, prior to the spring growing season.

The seawards sequence would involve excavating the shore approach trench in July, with backfilling completed by the second week of August. At this time of year, the natural die-back of the shoots, and replenishment of energy reserves in the below-ground organs would not have taken place. The rate of survival of the plants during the period when plants are stockpiled or covered, and subsequent recovery rates may, therefore, be lower.

Monenco Pipeline Consultants Ltd. anticipate that some of the dredged material will be lost through wave erosion, thus creating a deficit in backfill material that would need to be imported. This "foreign" material, being comprised mostly of sands, should be deposited at the bottom of the trench so that the original organic material stockpiled for the purpose of trench restoration is deposited at the surface of the trench.

Depending on the skill with which the trench is backfilled, some variation in the finished elevation is expected. It is preferred that the trench be left slightly short of material rather than overfilled, as most of the native marsh plants prefer slightly wetter conditions. On slightly higher and drier sites, weed species would tend to colonize. As well, in the sheltered marsh environment, it is more likely that sediment will become trapped in depressions than erosion will to occur on slightly elevated sites.

7.4 Impacts on Wildlife

7.4.1 Introduction

Wildlife habitats crossed by the pipeline route on Roberts Bank include the intertidal sandflats, Canoe Pass, and the Brunswick Point marsh. There are roughly 700 ha of foreshore marsh on Roberts Bank, of which 164 ha are included in the Brunswick Point marsh. Snow geese and dabbling ducks are the most prevalent users of these marshes. Brunswick Point is cited as the single most important foreshore area for wintering snow geese, and is also an important habitat for swans.

Impacts on wildlife could arise from direct disturbance during construction, and indirectly as a result of habitat disturbance. Direct impacts, manifested in the temporary displacement of wildlife, could occur as a result of noise and other disturbance generated by the movement of equipment, manpower, supplies, etc. This disturbance would only persist for the duration of the construction period, and is not expected to incur any measurable long-term effects.

Indirect impacts on wildlife may occur as a result of loss or disturbance to wildlife habitat. The vegetated foreshore area is the most critical wildlife habitat on Roberts Bank, thus the potential disturbance to the marsh during construction, and the degree and rate of plant recovery, is of some concern.

In light of these general comments regarding the nature of potential wildlife impacts, a more detailed discussion of impacts associated with the different wildlife habitats on Roberts Bank is provided.

7.4.2 Foreshore Marsh

The foreshore marsh is important for wildlife as it provides a source of food critical to the diet of snow geese, swans and dabbling ducks, and shelter or nesting sites for several other species of birds.

The pipeline would cross the marsh at its narrowest point, at the northeast corner of the marsh, potentially disturbing about 2.4 ha of marsh habitat.

The section of marsh that would be crossed by the pipeline is a mature part of the marsh, and of somewhat less value to waterfowl than the more dynamic outer portion of the marsh. The preferred route for crossing the marsh, by avoiding all but a small portion of the upper marsh, would avoid any direct disturbance to waterfowl using the more productive, outer fringes of the marsh. It is recognized, however, that construction activity will generate a certain amount of noise and will result in some degree of disturbance to waterfowl. This effect will be temporary, and it is expected that the birds would simply move slightly farther offshore if the construction activity constitutes a significant disturbance factor.

The degree to which the potential loss of approximately 0.34% of the Roberts Bank foreshore marsh would reduce wildlife use of this area is impossible to accurately measure, but if the affected marsh area was permanently lost, there would likely be a comparable reduction in the capacity of the delta to support dabbling ducks, swans and snow geese. Even though the Brunswick Point marsh has more than average importance for snowgeese in comparison to other foreshore areas, the impacts on this species are not expected to be greater than the proportion of habitat disturbed, as use by snow geese is concentrated in the outer marsh, and this will not be directly affected by construction.

7.4.3 Canoe Pass

This portion of the Roberts Bank crossing is of little significance as wildlife habitat. The use of Canoe Pass by wildlife generally involves feeding on migrating fish, and is concentrated during the spring when juvenile salmon and eulachon are present in the channel. The wildlife species that frequent this area are seals, mergansers loons, grebes and cormorants. As the proposed dredging schedules avoid Canoe Pass during the spring and early summer, no significant impact on piscivorous wildlife species is anticipated. Sandbars used by seals for haul-out sites are situated along the edge of Canoe Pass, downstream of the pipeline crossing, and would, therefore, not be affected unless portions of the banks were dredged for backfill in Canoe Pass.

7.4.3 Intertidal Sandflats

Wildlife use of the intertidal sandflats is primarily for loafing at low tide, and for feeding on benthic organisms. Construction across the sandflats is not expected to reduce the productivity of the intertidal area over the long term. Use of the intertidal sandflats by wildlife is not expected to be curtailed other than during the construction period when some temporary displacement of loafing or feeding birds would occur. Since the food capacity of the intertidal flats does not appear to be heavily used by wildlife, the impact of such displacement should be negligible.

7.4.4 Comparison of Construction Sequences

Of the three wildlife habitats identified on Roberts Bank, the foreshore marsh adjacent to Brunswick Point is by far the most important for wildlife, and hence construction activity is of much greater significance here than elsewhere. The timing of construction in the marsh and into Canoe Pass is significant, both in terms of direct disturbance to wildlife, and, indirectly, in terms of the potential alteration of habitat that could result from trenching through the marsh.

Seawards Sequence: For the seawards sequence, construction through the marsh would occur in July, and continue into August for the completion of backfilling the shore approach trench. Construction at this time of year could disturb some seals that use haul-out sites along the edges of

Canoe Pass, but these animals would likely move to other sites for the duration of construction.

Disturbance of key waterfowl species - snow geese and dabbling ducks - would be almost non-existent. Work in the marsh should be completed by September, when large numbers of dabbling ducks could be present. Snow geese do not generally start feeding in the marsh until October. Nesting by songbirds, such as marsh wrens, would be over before August. Construction activity would create a minor disturbance for herons and shorebirds, but overall, the seawards sequence is considered to have little direct impact on wildlife due to disturbance.

The impacts on the marsh habitat, and the consequences of timing in relation to restoration of the marsh, have already been addressed in Section 7.3.5, where it was concluded that the restoration of the marsh would have better chances of success if the vegetation was stockpiled and replanted in the late fall/winter period. Thus, from the perspective of potential impact on wildlife habitat, it is important that the marsh be successfully restored. The landwards sequence thus offers a better opportunity for successful restoration than the seawards sequence.

Landwards Sequence: For the landwards sequence, work in the marsh would be carried out in November and December. Although there would be no measurable effect on seals or songbirds, construction at this time would coincide with the period of peak concentrations of dabbling ducks and snow geese. Due to the regional importance of the Brunswick Point marsh for these waterfowl species, particularly snow geese, disturbance associated with construction activity must be considered a significant potential impact, albeit a temporary one.

7.5 Public Use

7.5.1 General

Two assumptions were made in the assessment of impacts. Firstly, those activities on which people depended for a livelihood were taken as having more importance than purely recreational activities. Secondly, impacts on activities tied to a fixed location were weighted more heavily than those where other opportunities for that activity were readily available. It is concluded that no long term impacts on public use of the area are anticipated as a result of the project.

7.5.2 Commercial Fishing

Construction on Roberts Bank in the period from late June to mid-October would interfere with commercial salmon fishing only when a 'full river' opening was permitted. There would be no interference if fishing were restricted to areas west of the Blue Line or Georgina Point Line (see Appendix 6, Figure 2).

The presence of the laybarge in Canoe Pass in September through October would probably restrict passage of fishing boats for that period.

The crab fishery on Roberts Bank is concentrated along the upper part of the foreslope. The pipelaying and dumping activity on the foreslope would require removal of any crab pots along about 1 km of the foreslope, decreasing crab harvesting opportunity, except to the extent that construction coincides with the "soft shell" crab fishery closure.

The construction activity on the foreslope may result in a temporary reduction of the crab population in that part of the foreslope due to dredging, dumping of excess fill and pipelaying activity.

The obstruction of Canoe Pass in September and October would require crab fishermen based in the Ladner area to detour north of Westham Island to reach crab fishing areas on Roberts Bank, incurring extra expense in fuel and time.

As the shrimp and ground fisheries occur in deeper water west of Roberts Bank, no impact on these activities is anticipated. A 1981 regulation restricts trawling to that area west of the 50 fathom contour along the delta foreslope.

The pipeline would be buried to the -23 m contour, and would lie partially embedded in the seabed west of this point. Studies by B. C. Hydro have shown that, given the small diameter of the pipes, and their protective concrete coating, the pipes would not be an obstruction to trawl nets. The size of the otter boards that are used locally is not sufficient to cause damage to the pipelines.

At present, the Indian food fishery in Canoe Pass is licensed to occur between mid-March and the end of October; its western boundary is a line from Brunswick Point tangential to the west side of Westham Island.

There will be no impact on this fishery, as construction east of the line is not scheduled until mid-November, unless weather conditions are so favourable that construction is ahead of schedule, or unless dredging activity in

Canoe Pass Channel could cause fish to divert to the South Arm. The probability of this is not known.

6.5.3 Recreation

The tidal currents and wave conditions on Roberts Bank do not make it as attractive for sports fishing as many other available areas. As Area 29 is presently closed for sport fishing for chinook salmon, this further depresses sport fishing activity on Roberts Bank (see Figure 2, Volume 5).

As construction will be confined to a limited area of Roberts Bank at any given time, no significant impact on sports fishing is anticipated, except for the short period when Canoe Pass will be closed to boat access. As this is expected to be late in the year, even this impact is only minor, in terms of numbers of fishermen affected.

As very little recreational crabbing occurs in the vicinity of the pipeline route, the project is not expected to have any adverse effects on the opportunities for crabbing.

Brunswick Point and its adjacent marshes are a very important area to duck and goose hunters in the fall and winter, and to the naturalists who come to watch these and other birds, as it is one of the few areas of foreshore marsh with public access.

The potential impact on hunting is temporary but serious, in that for the landwards sequence, construction activity, including demobilization of equipment, would occur at Brunswick Point from 1 November to 15 February. If it is assumed that the construction area would be closed to hunting, it is probable that the northern portion of

Brunswick Point marshes would be closed to hunting for one season. The imposition of a partial or total hunting closure at Brunswick Point is at the discretion of the Canadian Wildlife Service and the Fish and Wildlife Branch. A closure may not, in fact, be necessary. Bird watching activities would be limited to the extent that birds are displaced due to disturbance from construction activities in and near the marsh.

Other recreation use of the project area is virtually confined to the dyke, which provides opportunities for walking, cycling, horse riding, and nature observation. Use of the dyke at Brunswick Point would be disrupted by construction and tie-in of the land and marine pipelines. As this work would occur between November and February, the major group of users that would be affected is that associated with bird-watching activities. Summer activities would not be affected. Small boat access to the marsh from Brunswick Point would likely be curtailed for a brief period, but can be achieved at other locations along the dyke.

6.5.4 Marine Traffic

The major volume of marine traffic in the study area uses the deepwater shipping lane paralleling the head of the foreslope for access to Vancouver Harbour and the South Arm of the Fraser River. This traffic would not be affected by construction on Roberts Bank. Pipelaying down the foreslope and across Georgia Strait would result in the laybarge crossing the designated shipping channels. It is understood that these can be temporarily adjusted to accommodate construction of the pipeline.

Construction across Roberts Bank would not interfere with marine traffic until the construction train enters Canoe Pass in mid-October. Its presence in the channel would curtail use by all marine traffic other than very small boats until backfilling of the trench in Canoe Pass is completed in mid-December.

During this construction period, average daily transits of Canoe Pass, based on openings of the Westham Island bridge in 1980, varied from 9 in October to 2.7 in December. These figures may be slightly underestimated, as they do not include any transits stopping at the Wes-Del Marina west of the bridge. It was established by contact with the local marina operators and fishermen that closure of Canoe Pass in the late fall and winter period would have the least effect on marine traffic in Canoe Pass.

7.6 Analysis of Impacts

It was earlier mentioned that the greatest opportunity for avoiding or minimizing potentially adverse effects of pipeline construction lay in the flexibility of the construction schedule. Having identified the various impacts associated with pipeline construction activities, and compared the severity of those impacts at different times of the year, particularly with reference to the landwards and seawards construction sequences, it was concluded that the landwards sequence would incur a significantly lower level of environmental impact than the seawards sequence, and offered a greater degree of security for equipment and personnel, and lower costs, in terms of the construction process itself.

Given the length of time required to construct the pipeline across Roberts Bank, it would not be possible to avoid or minimize potential impacts on all resources or resource uses given one continuous construction phase. Therefore, as with most major construction projects spanning a considerable length of time and interacting with a complex natural, and to a lesser extent man-made environment, certain trade-offs between the various potential impacts were made to achieve the project in a sensible and efficient manner. The following paragraphs describe the rationale underlying these trade-offs, and the reasons behind the decision to adopt the landwards construction sequence.

Construction Considerations

In terms of ease of construction, the landwards sequence is much preferred over the seawards sequence, primarily because it would allow construction on the foreslope and the outer portion of the intertidal flats to proceed during the summer, when weather conditions would be most favourable. Due to the fact that the foreslope and intertidal flats are very exposed, construction along this section of the route would be most vulnerable to bad weather, which in turn would increase the frequency of downtime and, therefore, costs. With the landwards sequence, winter construction would occur inshore, in the more sheltered environment of Canoe Pass and near Brunswick Point.

In contrast, the seawards sequence would start at Brunswick Point in early July, and proceed offshore, reaching the outer portion of the intertidal flats and foreslope by late December. Thus, the most difficult section of the route would be constructed during the winter months, when the risks of bad weather are relatively high, and therefore the frequency of downtime is expected to be greater.

Environmental Considerations

Of the four habitat zones crossed by the pipeline route, the marsh habitat near Brunswick Point, and the riverine environment of Canoe Pass, are the most sensitive to pipeline construction activities, particularly dredging. In comparison to the intertidal sandflats and the delta foreslope habitats, the nature and timing of the use of these areas by fish, wildlife, and humans is fairly well understood. Thus the nature and severity of potential impacts on the marsh and in Canoe Pass can be predicted with a reasonable degree of accuracy.

Brunswick Marsh and Canoe Pass

Of primary concern in Canoe Pass and in the marsh itself are the potential impacts on juvenile salmon if they should become entrained in the dredging process. The annual downstream migration of juveniles has been well documented and is summarized in Kistritz's report. The run starts in early March and tapers off by the end of May, although juveniles have been observed in the area as late as the first week of July. To avoid interfering with the juvenile migration, and in recognition of existing dredging guidelines for the Fraser River, and those imposed more recently for dredging at the Roberts Bank coal port, February 28 was adopted as the date on which dredging must terminate in Canoe Pass and the Brunswick Point marsh.

In terms of the landwards sequence, there would be a definite risk of running out of time to complete construction in one season. The start date on the foreslope therefore became a critical factor in choosing to adopt this sequence.

The upstream migration of adult salmon was of slightly lesser concern than the downstream migration of juveniles because the adult salmon are more capable of avoiding the hydraulic dredge. If, however, Canoe Pass was blocked during the upstream migration, the resulting delay in the movement upstream may have serious consequences for the stocks, depending on the extent to which fish would re-route themselves up the Fraser River. The upstream migration is less predictable than the downstream migration of juveniles, but it usually extends from about mid-June to as late as November, with the peak runs occurring in August, September, and October.

For the landwards sequence, dredging in Canoe Pass would begin around the middle of October; for the seawards sequence, by the middle of July. Clearly, the landwards sequence is preferable as it may only interfere with the tail end of the spawning runs, depending on the timing and strength of the runs in the year of construction.

Wildlife use of the Brunswick marsh and inshore intertidal areas has been summarized in Section 7.4, where it was noted that the landwards sequence would coincide with peak concentrations of dabbling ducks and snow geese in November and December. Direct disturbance of these key waterfowl groups would be almost non-existent if construction through the marsh occurred during the summer months. From the perspective of direct disturbance to waterfowl, therefore, the seawards construction sequence would be preferred.

The impact on the marsh itself represents a potential long-term impact unless adequate restoration procedures are carried out. To a large extent, success of restoration will depend on the time of year that the vegetation is removed and stockpiled. The marsh vegetation goes into dormancy in late fall and winter, during which time the energy and nutrient reserves are stored in the roots. Excavation of the marsh during the dormant phase would, therefore, result in least disturbance to the marsh habitat, as most of the above-ground shoots would have died, and stockpiling and re-planting the natural vegetation would occur prior to the spring growth period. The landwards sequence would involve construction through the marsh during the dormant phase and is, therefore, preferred over the seawards sequence in which work in the marsh is scheduled for July.

From the perspective of public use of Canoe Pass and the area at Brunswick Point, the optimum construction window would be between the middle to end of March, and the middle of June. This would avoid the hunting season which closes on the 10th of March, and the commercial fishing season which usually begins around the middle of June. It is also a relatively inactive period for crab fishermen as the "soft-shell" closure is in effect usually between mid-May and mid-June. Boat traffic using Canoe Pass is mostly associated with commercial and sport fishing, and would, therefore, experience much less disruption as compared to later in the summer and early fall. However, construction at this time of year would clearly be in conflict with the downstream migration of juvenile salmon. As this was considered to be a much more serious potential long-term impact than any temporary disruption of human activity in the area, the optimum schedule from the point of view of public use was unacceptable.

The seawards and landwards sequences were compared, and it was concluded that the seawards sequence would entail more disruption to public use, for the following major reasons:

1. Closure of Canoe Pass between mid-July and the end of August would coincide with the commercial salmon fishery, resulting in a restriction to fishing activity near the mouth of Canoe Pass which may or may not be a factor depending on the fishing closures at the time, and blockage of access to Georgia Strait for fishermen who would normally use Canoe Pass;

2. Closure of Canoe Pass would also coincide with the peak period of activity for commercial crab fishermen - this is a problem of disruption of access for fishermen, but would not curtail crab harvesting along the crest of the delta foreslope; and

3. Closure of Canoe Pass would occur at a time of peak traffic volumes in Canoe Pass, reflecting not only commercial salmon and crab fishing activity, but also sport fishing and pleasure boating activity.

In contrast, the landwards sequence would require closure of Canoe Pass in the late fall and winter, from about mid-October until the end of December. At this time of year, traffic volumes in Canoe Pass would have diminished, the commercial salmon fishery would have ended, and crab fishing activity would have dwindled as compared to the summer months. Landwards construction would, however, result in construction through the marsh during the hunting season. Brunswick Point is a popular public hunting and bird-watching area; however, the closure on hunting activity during construction, and disruption of other waterfowl-related recreation for approximately two months, cannot be considered as a serious impact.

Intertidal Sandflats

The major potential impact on the intertidal sandflats is the destruction of benthic organisms along the pipeline route. There are no obvious spatial or temporal variations in benthic communities across the sandflats; therefore, impacts are expected to be relatively uniform and unavoidable. Benthic communities are expected to recover within about one year after dredging.

Fish are present at all times during the year; therefore, some fish mortality as a direct result of construction activity is inevitable. Potentially adverse effects on salmon can be minimized if dredging across the sandflats and delta foreslope is scheduled between September and the end of January. In addition, other measures can be taken to deter fish from entering and remaining in the bathtub, as discussed in Section 10.

Dredging across the sandflats would have little effect on wildlife, as this area is of relatively minor importance for wildlife habitat. Opportunities for feeding on invertebrates during higher tides and for loafing on sand bars at low tides should not be significantly reduced after project completion.

The presence of dredging and pipelaying equipment in an otherwise uninterrupted marine environment represents a temporary physical obstacle for marine traffic in the surrounding waters. There is an obvious seasonal variation in marine traffic due to fishing and recreational boating activity that peaks during the summer. The potential disruption to marine traffic was not considered to be a significant impact, as smaller boats would be capable of avoiding the construction area, and the commercial shipping lanes are farther offshore and should not be affected by this portion of underwater pipeline construction.

In conclusion, from an environmental point of view, construction across the intertidal flats does not appear to be a critical issue in terms of the scheduling. From the perspective of ease of construction, there is, however, a clear preference for the landwards sequence to take advantage of favourable weather conditions while out on the sandflats.

Delta Foreslope and Outer Intertidal Sandflats

In general, the nature and severity of potential impacts on the delta foreslope and outer portion of the intertidal flats are less well understood than those associated with Canoe Pass or the marsh.

The major potential environmental impact in this area is associated with Dungeness crab populations that are present along the pipeline route at several times during their life cycle. Crabs are most vulnerable during their moulting phase, during which time they are least mobile and are without their protective exterior shell. "Soft shell" crabs can be found along the foreslope from about April to the end of September. In July and August, adult crabs are aggregated for reproduction in the shallower waters of the foreslope, and stand to be affected by dredging at that time.

Clearly, it would be desirable to avoid dredging on the foreslope during the soft-shell period, and for this reason, the seawards schedule would be preferred since dredging on the foreslope and lower intertidal zone would be completed prior to the moulting and mating period.

The landwards sequence is proposed to start dredging on the foreslope in mid-June, and could interfere with the soft-shell period. The early start date for dredging was justified, however, given the much more serious consequences of running out of time in the inshore areas when the juvenile salmon stocks migrate downstream through Canoe Pass.

Other potential impacts in the foreshore area are of comparatively minor importance, and are similar to those cited for the intertidal sandflat habitat.

Conclusions

The landwards construction sequence, whereby dredging would start on the delta foreslope in mid-June, and be completed through the Brunswick Point marsh by the end of December, was adopted by the consultants as the preferred sequence. In summary, the major reasons for this choice are:

1. this schedule takes advantage of favourable weather conditions during construction along the exposed, outer portions of Roberts Bank;
2. it avoids all potentially critical impacts, particularly the downstream migration of juvenile salmon through Canoe Pass;

and 3. it either avoids or minimizes many of the temporary, and somewhat less important impacts that have been identified in the course of this study.

The preference for the landwards sequence assumes that dredging in Canoe Pass and the adjacent marsh will be terminated by 28 February, and under no circumstance would be permitted to extend beyond this date until the downstream migration of juvenile salmon had finished, which is usually by the end of May. The preference for the landwards sequence further assumes that dredging on the delta foreslope will not be subject to the same environmental and regulatory constraints as those for Canoe Pass, and that the critical period for dredging on the foreslope is primarily associated with the occurrence of soft shell crabs. As far as can be determined, this critical period lies roughly between 1 April and September.

The preference for the landwards sequence, therefore, recognizes the following key elements:

1. That a 60 day contingency period be incorporated into the schedule in the event that lengthy delays occur due to major equipment failures, strikes, etc.

2. The early start date on the delta foreslope is justified, even though this may incur a potentially greater impact on the crab resources, because it allows for the additional 60 days, should this be required, rather than incurring the risk of running out of time as the 28 February dredging deadline is approached.

3. If the start date of 15 June cannot be achieved, then the seawards sequence must be reconsidered. The seawards sequence is much less favourable in terms of increased weather downtime, interference with the upstream salmon migration through Canoe Pass, interference with the peak period of fishing and boating activity, and timing of the storage and re-planting of marsh vegetation.

8.0 MITIGATION AND COMPENSATION MEASURES

8.1 Scheduling and Construction Sequence

Adjustment of the schedule and construction sequence allows some variation in the distribution of impacts.

Adoption of the landwards construction sequence and proposed schedule would minimize the potential impacts on fish resources and the hazards to those involved in construction. It would incur some loss of crabs during the soft shell period, increased disturbance of wintering waterfowl near Brunswick Point and the loss of a season of duck and goose hunting at Brunswick Point.

These adverse impacts cannot be easily avoided as the schedule cannot be significantly adjusted without requiring dredging during the period of juvenile fish migration. This was considered unacceptable.

The only alternative to the landwards construction sequence is the seawards sequence, or a two-year construction period. The seawards sequence is assessed as having higher impacts and posing greater hazard to men and equipment during construction.

A planned, two-year construction period, using the landwards sequence, would probably involve a halt in construction when pipelaying reached Canoe Pass in October, to avoid disturbance to wintering waterfowl, and resumption of construction on 1 July in the following year with completion in October. While the impacts on waterfowl would be reduced, there would be extra impacts resulting from waste disposal outside the "bathtub" as the previous "bathtub" would have to be re-dredged to allow construction to resume. The costs would escalate by about 25%, due to the extra costs of re-mobilizing the construction equipment, and the costs associated with re-locating the buried pipe ends where construction had left off the previous year.

For these reasons, the proposed landwards construction sequence and schedule are considered to offer, on balance, the best method to avoid, or minimize anticipated adverse environmental and social impacts.

8.2 Construction Techniques

It is recognized that adverse impacts on the Brunswick Point marsh and on fisheries can be reduced through reduction of the amount of fine material allowed to wash out of the dredgeate during deposition. Experiments would be done during the early period of construction to determine the most effective techniques for reducing the loss of fines; these would include use of splash plates, conical discharge nozzle, vertical discharge, etc.

It has been suggested that the "bathtub" may be used by fish as a refuge during the low tidal cycle, with a resulting loss of fish during dredging. If such losses occur, efforts would be made to keep fish away from the "bathtub", particularly at the suction head, and to adjust dredging techniques to minimize the intake of fish into the suction head.

8.3 Crabs and Crab Fishery

Dredging at the head of the foreslope would result in some mortality of adult crabs, particularly if dredging coincides with the "soft shell" period. This loss could be mitigated by an extended closure of crab fishing in the vicinity of the pipeline to reduce the harvest of crabs until the estimated losses due to construction were recovered. Such a closure would, however, adversely affect the crab fishermen, whose activities would be curtailed.

Furthermore, the closure of Canoe Pass during the crab fishing season would disrupt access to Roberts Bank for those fishermen who normally use Canoe Pass. The extra costs incurred by the crab fishermen as a result of a two month closure of Canoe Pass from mid-October to mid-December are clearly attributable to the project and would be compensated both in terms of travel costs and workers' time.

It is not clear that the loss of crabs due to dredging would measurably reduce the numbers of crabs taken from Roberts Bank in any year as there is no limit to the take in any year, other than legal size limits, and the take has fluctuated from year to year. Hydro proposes to reduce crab mortality (as a result of dredging) through removal of crabs from the pipeline route prior to start of dredging at the foreslope. It is expected that crabs will re-colonize the affected area within one year.

8.4 Waterfowl and Hunters

Waterfowl would suffer some disturbance due to construction activity in the inshore intertidal area and at Brunswick Point from October through December. Although it is anticipated that no permanent impacts on wildlife habitat would occur, as the marsh would be restored, there would be some temporary disturbance to waterfowl. The construction activity and transport of crews and supplies to the construction spread would create a zone of disturbance, although it is not well understood how extensive this "zone" would be, nor the effects of disturbance on certain sensitive waterfowl species.

The disturbance generated from construction activity will likely cause some species of birds to move away from the construction area, and may, indirectly, reduce the immediate opportunities for hunting and birdwatching at Brunswick Point. If it was considered necessary for reasons of safety to close the public hunting area at Brunswick Point, hunters who normally use the area and adjacent marshes for hunting would lose virtually all hunting opportunities for one season. If it is felt, however, that the risk of injury to construction workers and equipment is insufficient to warrant a hunting closure, then B. C. Hydro is prepared to accept the decision of the Fish and Wildlife Branch on this matter.

As partial compensation for any residual impacts on public use as a result of the temporary disruption of recreational activities at Brunswick Point, Hydro is prepared to contribute to creating some additional parking space adjacent to the valve station for the use of all recreational users.

8.5 Recreation Other Than Hunting

The impacts of project construction can best be mitigated through appropriate timing of construction in the key areas of Canoe Pass and Brunswick Point. Apart from a certain amount of temporary disruption to hunting and birdwatching activities near Brunswick Point during the late fall and winter, there are no other significant impacts on recreational use associated with the proposed sequence and schedule.

It is considered that the most appropriate mitigation and compensation for the limited residual impact would be the provision of the parking area proposed in Section 8.4.

8.6 Benthic Community

It is recognized that a major loss of benthic organisms will occur along the pipeline route. No way of mitigating this is known other than to use as short a route as is possible, subject to other restraints, and to backfill is such a way so as to re-establish original topography and stability. As this has been done, no further mitigation is possible.

Given the nature of the loss, no direct compensation is payable to any party. However, recognizing the singular scientific and ecological importance of Roberts Bank, and the lack of data on the behaviour of the benthic portion of its ecosystem, B. C. Hydro is prepared to contribute funds to a scientific agency to execute monitoring studies of benthic populations pre- and post-construction, on the condition that the results of such studies are published within three years of completion of construction.

8.7 Marsh Restoration

As stated in Section 6.3, some 2.4 ha of tidal marsh at Brunswick Point will be disturbed during construction of the pipeline. The ecological importance of the marsh is recognized, together with the need to secure prompt revegetation of the disturbed area to prevent degeneration of the adjacent marsh areas through regressive erosion, and to restore food production from the marsh.

B. C. Hydro proposes, therefore, to revegetate the disturbed area of the marsh, using the following steps:

1. Prior to the start of construction the vegetation zones in the area to be disturbed will be identified on the ground and sufficient plugs (approximately 10 cm x 25 cm) and small mats (approximately 50 cm x 100 cm x 10 cm thick) will be cut from each zone to allow the zone to be replanted at a minimum density of 1 plug/m^2.

2. The plugs and mats will be labelled and stored off-site, in conditions suitable for their survival.

3. The top organic layer (approximately top 25 cm) will be stripped off the trench and stored adjacent to the stockpiled vegetation using appropriate equipment, such as bulldozers or drag lines.

4. On completion of the backfill in the trench, the stored organic material will be spread over the trench.

5. The original vegetation zones will be marked out and the plugs and mats placed in each in a manner consistent with their origin.

6. The site will be monitored at frequent intervals through the remainder of winter following completion of construction, to assess, and if necessary, guard against excessive erosion. From 1 April to 1 December, the site will be monitored at monthly intervals to determine the effectiveness of the restoration measures. In the second year it will be monitored quarterly, and a report will be prepared on the revegetation progress observed.

It is estimated that this work will cost the following:

Vegetation mapping		$ 2,000
Plug cutting and storage		50,000
Surface stripping		63,000
Surface restoration		110,000
Plug planting		60,000
Monitoring -	First winter	20,000
-	Remainder of 1st year	25,000
-	Second year	20,000
-	Report	20,000
-	Total Approx.:	$370,000

8.8 Selection of Service Docks and Sites

B. C. Hydro will reduce impacts on existing waterfront users by selecting sites for coating and storage of pipe, and transfer of crews and materials, that minimize interference with normal commercial operations.

9.0 CONCLUSIONS

1. It is concluded that it is possible to construct the project along the route proposed, using the bathtub method, without causing irreversible negative impacts on the environment.

2. The total level of environmental impact can be minimized by use of the landwards sequence of construction and the related construction schedule.

3. Assuming the proposed route, construction method, sequence, and schedule, the major permanent environmental impacts are as follows:

   - Excavation, translocation and deposition of 2,750,000 m^3 of alluvial deposits in a different stratigraphic pattern along the pipeline route;
   - Reduction in the proportion of fines in the backfill material redeposited in the pipeline trench;
   - Dispersal of about 130,000-210,000 m^3 of fines into the water column during dredging and deposition. It is assumed most of this will be distributed over the banks and into the marshes;
   - Placement of four trench plugs, totalling about 26,000 m^3, of material coarser than the adjacent material, two of which would be placed on the foreslope and two at the north side of Canoe Pass;
   - Dumping of about 180,000 m^3 of alluvial deposits on the foreslope;
   - Incorporation of two buried pipelines into the alluvial deposits of Canoe Pass and Roberts Bank;
   - Changing the nature of subsurface sediments to a depth of up to 7 m in 0.85 ha of Brunswick Point tidal marsh;

- Some loss of fish and crabs due to entrainment during dredging.

4. With the same assumptions as in (3), the major temporary environmental and resource use impacts are as follows:

   - Reduction in benthic populations of dredged areas until recolonized; recovery of benthic communities is expected to take approximately one year;
   - Disturbance of wintering waterfowl in vicinity of Brunswick Point;
   - Disruption of 2.4 ha of tidal marsh at Brunswick Point, and reduced productivity during period of restoration;
   - Extra travel costs to boaters using Canoe Pass to access Georgia Strait during period of construction in Canoe Pass;
   - Possible disruption of recreation opportunity on Brunswick Point dyke for about two months during winter season;
   - Adjustment in shipping lanes off Roberts Bank during tie-in and pipe laying on foreslope.

10.0 CONSULTANT RECOMMENDATIONS AND B. C. HYDRO RESPONSE

10.1 Physical Impacts

(a) Consultant - Adopt proposed route
B. C. Hydro - Agree

(b) Consultant - Bury pipe 7 m inshore, 5 m offshore
B. C. Hydro - Agree

(c) Consultant - Adopt 'bathtub' method of construction
B. C. Hydro - Agree

(d) Consultant - Adopt landwards construction sequence
B. C. Hydro - Agree

(e) Consultant - Adopt construction schedule proposed for landwards sequence
B. C. Hydro - Agree

(f) Consultant - Adopt proposed construction method for landing at Brunswick Point
B. C. Hydro - Agree

10.2 Aquatic Impacts

(a) Consultant - Adopt landwards construction sequence and related schedule
B. C. Hydro - Agree

(b) Consultant - Undertake the following monitoring programs:

1. The Brunswick marsh shore approach area should be surveyed prior to construction, supervised during

vegetation stockpiling and backfilling, and monitored after restoration to determine the success of restoration and to provide the necessary feedback information needed to determine if additional plantings or erosion protection measures should be undertaken.

2. Preconstruction surveys of benthos should be conducted along the route followed by post-construction monitoring to determine rates of recovery of benthic communities. This monitoring study would provide valuable case history information in assessing the environmental impact of a repair procedure in the remote chance that one of the pipelines is damaged. The monitoring results would also be of value in other future environmental impact assessments pertaining to disruptions of Fraser estuary tidal flats.

3. Measurements of entrainment and mortality of fish and crabs via dredging would provide useful case history information as well as providing a valuable assessment of techniques used in this project to minimize fish and crab entrainment in the dredging process.

B. C. Hydro -

1. The recommendation is accepted

2. The recommendation is accepted subject to mutual agreement between B. C. Hydro and the Order-in-Council 908 Technical Committee on the scope of the work to be done, the agency to undertake the work, and the publication of the results.

3. The recommendation is accepted subject to mutual agreement between B. C. Hydro and the Order-in-Council 908 Technical Committee on the necessary periods and location of monitoring to obtain adequate results.

4. Consultant - Due care should be taken in the handling, storage, and transport of polluting chemicals, such as petroleum hydrocarbons. Appropriate clean-up and containment equipment should be available.

B. C. Hydro - Agree

10.3 Wildlife Impacts

(a) Consultant - Adopt landwards construction sequence Use of the seawards sequence would avoid direct disturbance to wildlife, but in terms of overall wildlife population maintenance, habitat restoration is more important than one season of localized disturbance.

B. C. Hydro - Agree

(b) Consultant - Restore disturbed area of tidal marsh

B. C. Hydro - Agree

(c) Consultant - Minimize construction period in, and adjacent to, the marsh.

B. C. Hydro - The proposed schedule for landwards construction reflects the need to have a quick effective operation from the time of entry to Canoe Pass to completion.

(d) Consultant - Noises from construction machinery should be muffled to whatever extent is feasible. Movement of crew launches, tugs and barges should be as infrequent as possible and confined to the work area. Use of helicopters and hovercraft should be avoided if possible. If not possible, movements of those craft should also be restricted to the work area.

B. C. Hydro - It is intended at this time that work crews will be moved to the laybarge and dredge from a float in Canoe Pass. There will be movements every change of shift; usually this will be by launch but from time to time it may be necessary to use a helicopter or hovercraft if wave or tidal conditions prevent use of small boats.

Pipe will be moved to the laybarge using shallow draft tugs and scows from a yards on the Fraser River or Burrard Inlet, or Vancouver Island. These movements will occur every two to three days and will be highly dependent on tide and wave conditions.

Oil and other supplies will probably be moved to the dredge and laybarge by service boats from contractors' yards in Canoe Pass or farther up the Fraser River.
B. C. Hydro would favour use of the area along the Fraser near Steveston.

(e) Consultant - There should be tight control over habitat loss. The work area in the marsh should be as narrow as possible, and no activities should occur outside of it. If anchors must be placed in marshland outside of the work area, this should be done with great care. Within the work area, as much as possible of the surface soil layer containing roots and propagules of marsh plants should be stockpiled separately from underlying material and replaced on the surface when backfilling is completed. Pads on which land-based machines are placed should be of such design to cause minimal impact on the surface soil and roots or marsh plants.

B. C. Hydro - Agree

(f) Consultant - A serious attempt should be made to re-establish native plant species on the pipeline right-of-way through the Brunswick Point marsh. The urgency of this may depend upon the extent to which natural re-vegetation is expected to occur. For wildlife purposes however, it is not imperative that the entire disturbed area be immediately re-stocked with dense stands of rushes or sedges.

B. C. Hydro - The disturbed areas of the Brunswick Point marsh will be revegetated using native species.

(g) Consultant - Backfill material should not be obtained from locations that are currently important wildlife habitat. Backfill material placed within the marshlands should be of similar composition and quality to material already there: i.e. should be capable of supporting marsh plants.

B. C. Hydro - Concurs with the recommendation on location of backfill borrow areas. Backfill is required to fill the trench in Canoe Pass on completion of the landwards sequence. It is proposed to obtain that backfill from adjacent sandbanks in Canoe Pass.

Some imported backfill will be required in the disturbed area of the marsh. It is proposed that dredged river sand be used for the lower portion of the backfill, stockpiled soil from the excavation be used for the upper part, and the stockpiled vegetated material be replaced on top of the trench.

10.4 Public Use Impacts

(a) Consultant - Adopt landwards construction sequence and proposed related construction schedule.

B. C. Hydro - Agree

(b) Consultant - Recognize that project will interfere with established crab fishery on foreslope and compensate for extra costs to fishermen resulting from project.

B. C. Hydro - Hydro will publish notification to all mariners of the construction schedule and sequence of spread location prior to start of construction. The area of construction activity on the foreslope will be marked by a buoy three months prior to start of construction to allow the fishermen to remove all traps from the construction area.

Crab fishermen who are prevented from using their normal route through Canoe Pass by the dredge and laybarge will be compensated for the extra costs and time involved in detouring around the north end of Westham Island.

10.5 Further B. C. Hydro Proposals

In addition to the commitments made in response to consultant recommendations, B. C. Hydro proposes to make the following further commitments to be consistent with its established policies:

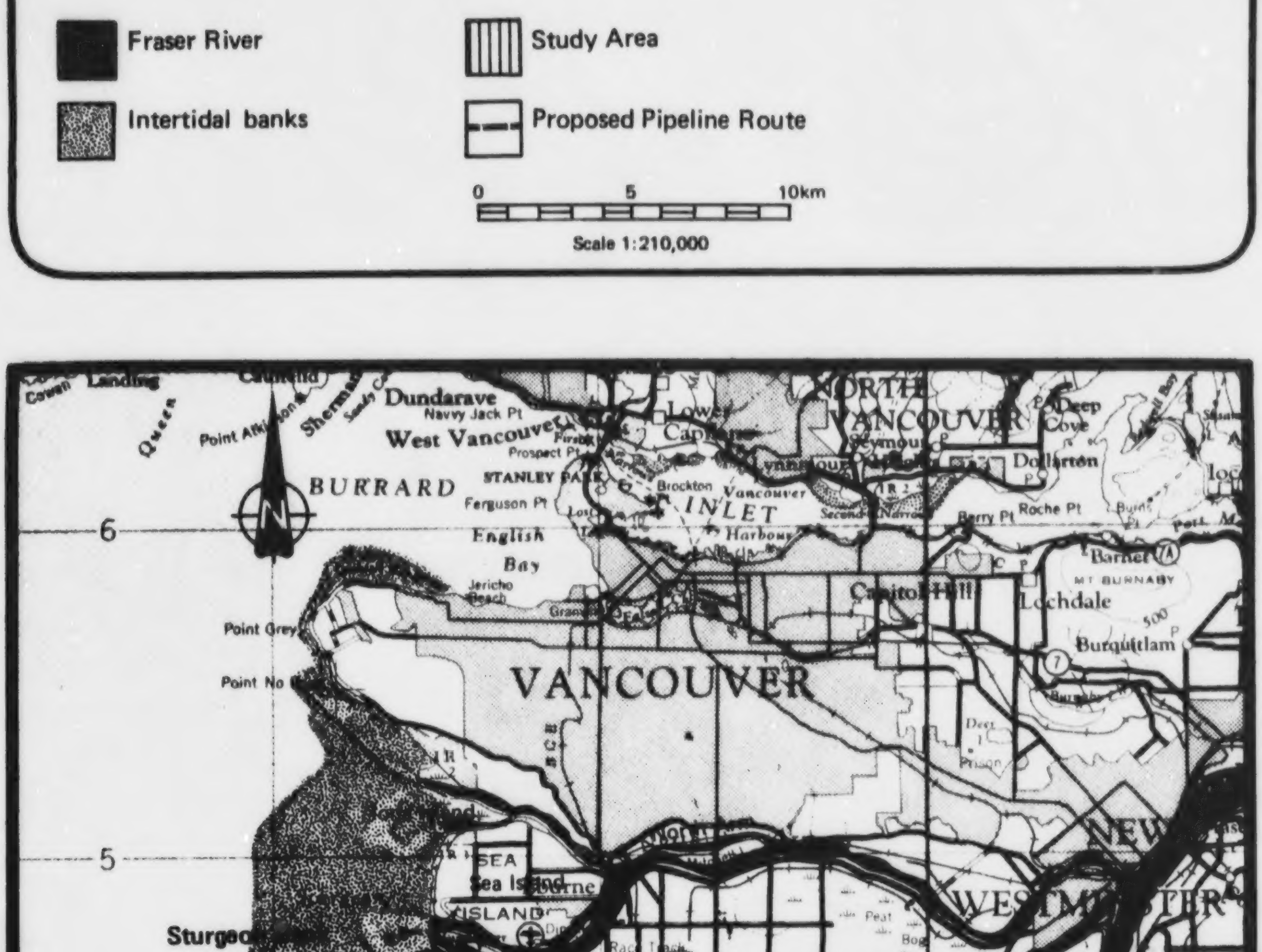
(a) B. C. Hydro will retain an environmental monitor, appropriately qualified, to direct all work related to the Brunswick Point marsh and its restoration.

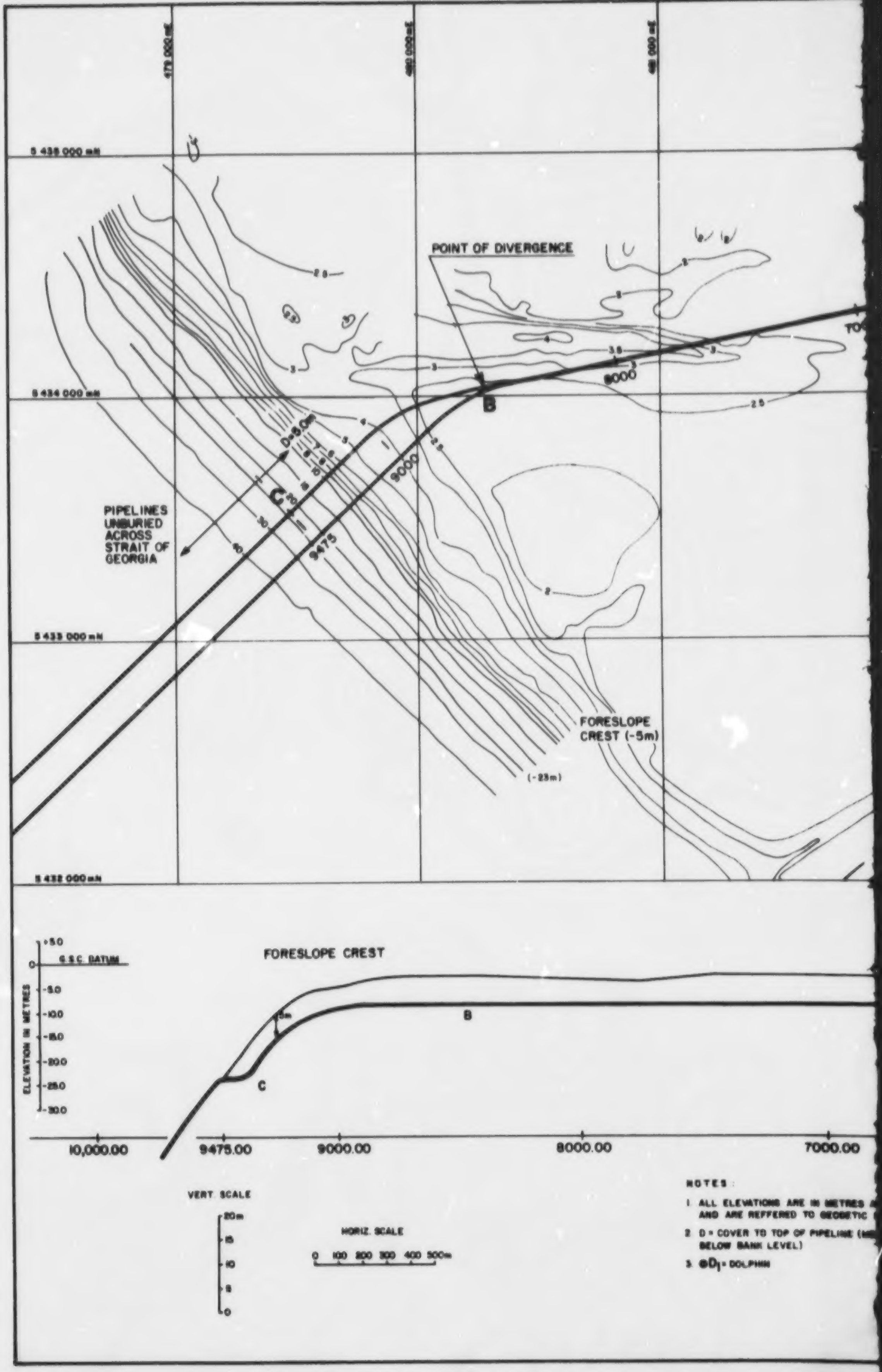
(b) B. C. Hydro will determine a detailed plan for the cutting of vegetation plugs, plug replacement and monitoring of the marsh area, and have these tasks executed as contracts separate from the main contract to permit greater control of the operations.

(c) B. C. Hydro will develop a small parking lot near the shore station at Brunswick Point for use of those visiting the area for recreation.

FIGURES

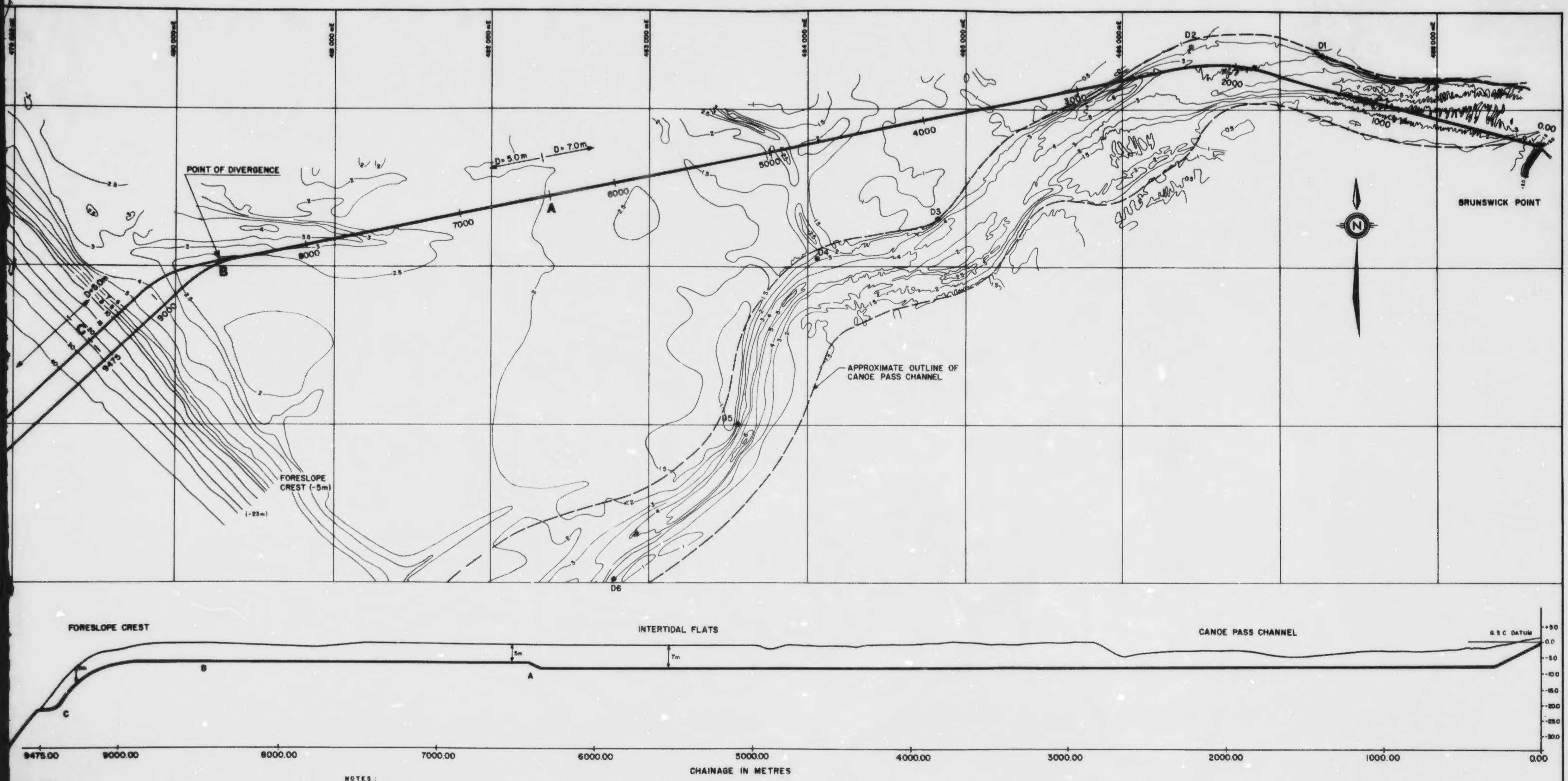
Study Area **Figure 1**


Fraser River
Intertidal banks
Study Area
Proposed Pipeline Route
0
5
10km
Scale 1:210,000
Dundarave
Navy Jack Pt
West Vancouver
Prospect Pt
Point Atkinson
Queen
BURRARD
STANLEY PARK
Brockton
Ferguson Pt
INLET
English Bay
Jericho Beach
Point Grey
Point No Point
VANCOUVER
NORTH VANCOUVER
Lower Capilano
Deep Cove
Dollarton
Second Narrows
Barry Pt
Roche Pt
Capitol Hill
Lochdale
MT BURNABY
Burquitlam
Barnet
NEW WESTMINSTER
SEA ISLAND
Sea Island
Sturgeon Bank
LULU ISLAND
Brighouse
Peat Bog
Race Track
Main Arm
Annacis I
Annieville
Strawberry Hill
Steveston
Harbour
Woodward Island
Tilbury I
Tp4
Tp6
Crescent Slough
Westham Island
Ladner
Guichon
Boundary Bay (abandoned)
Tp3
Tp5
Beach Grove
Sand Heads
Strait of Georgia
Roberts Bank
delta foreslope
Roberts Bank Coal Port CANADA
Boundary Bay
BAY
Kwomais Pt
6
5
4
3


479 000 mE
480 000 mE
481 000 mE
5 435 000 mN
5 434 000 mN
5 433 000 mN
5 432 000 mN
POINT OF DIVERGENCE
TO
8000
9000
9475
B
C
D=5.0m
PIPELINES UNBURIED ACROSS STRAIT OF GEORGIA
FORESLOPE CREST (-5m)
(-23m)
2.5
3
3.5
4
2
FORESLOPE CREST
G.S.C. DATUM
ELEVATION IN METRES
+5.0
0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
5m
10,000.00
9475.00
9000.00
8000.00
7000.00
VERT. SCALE
20m
15
10
5
0
HORIZ. SCALE
0 100 200 300 400 500m

NOTES:

1. ALL ELEVATIONS ARE IN METRES
AND ARE REFFERED TO GEODETIC
2. D = COVER TO TOP OF PIPELINE (
BELOW BANK LEVEL)
3. ⊙D1 = DOLPHIN


479 000 mE
480 000 mE
481 000 mE
482 000 mE
483 000 mE
484 000 mE
485 000 mE
486 000 mE
487 000 mE
488 000 mE
POINT OF DIVERGENCE
D= 5.0m
D= 7.0m
A
B
C
D=6.0m
9475
9000
8000
7000
6000
5000
4000
3000
2000
1000
0.00
D1
D2
D3
D4
D5
D6
BRUNSWICK POINT
N
APPROXIMATE OUTLINE OF CANOE PASS CHANNEL
FORESLOPE CREST (-5m)
(-23m)
FORESLOPE CREST
INTERTIDAL FLATS
CANOE PASS CHANNEL
G.S.C. DATUM
5m
7m
+5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
9475.00
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
2000.00
1000.00
0.00
CHAINAGE IN METRES
VERT. SCALE
20m
15
10
5
0
HORIZ. SCALE
0 100 200 300 400 500m

NOTES :

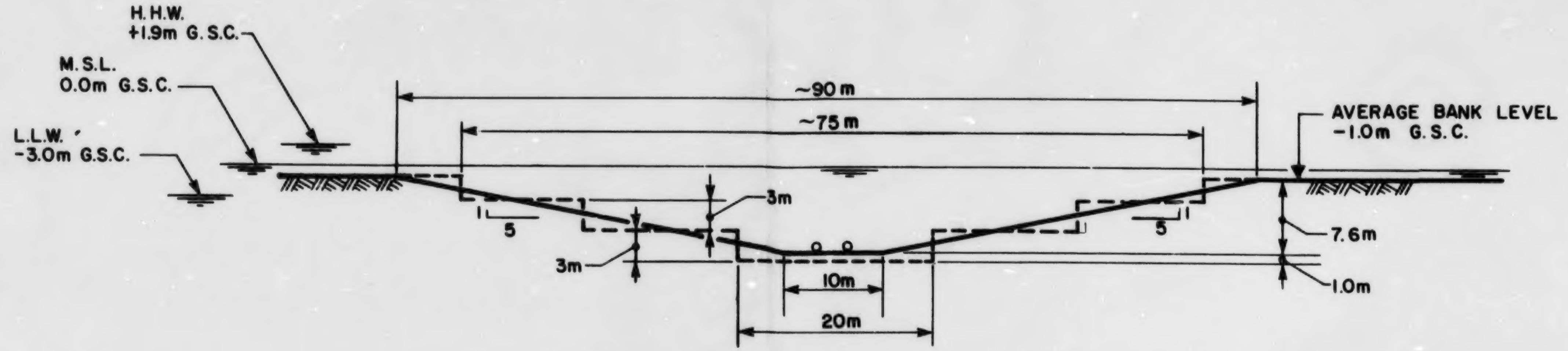
1. ALL ELEVATIONS ARE IN METRES ARE NEGATIVE, AND ARE REFFERED TO GEODETIC DATUM
2. D = COVER TO TOP OF PIPELINE (MEASURED AS DISTANCE BELOW BANK LEVEL)
3. ● D_1 = DOLPHIN

FIGURE 2

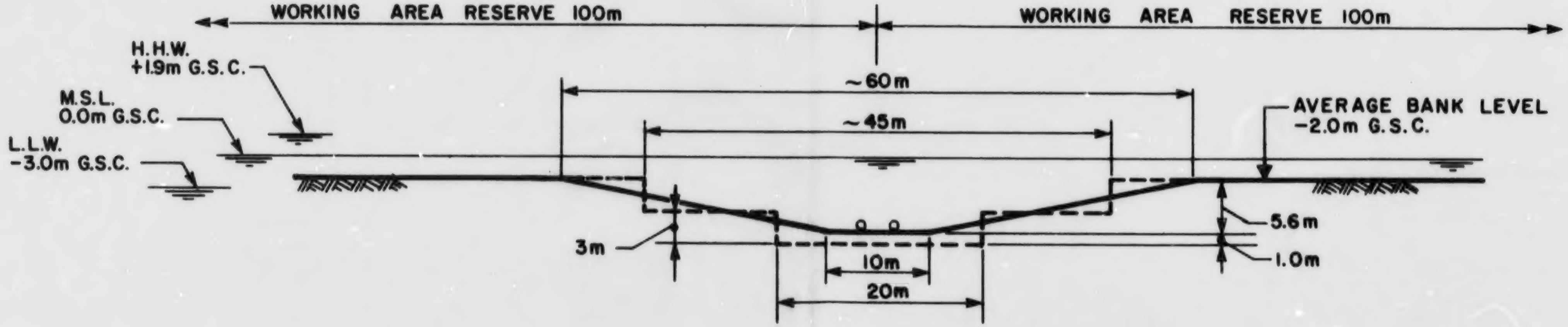
B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

ROBERTS BANK CROSSING
PIPELINE ROUTE AND PROPOSED PROFILE

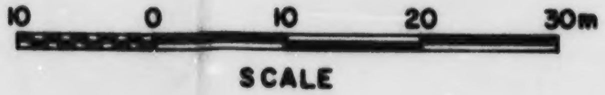
MONENCO PIPELINE CONSULTANTS LTD.


H.H.W.
+1.9m G.S.C.
M.S.L.
0.0m G.S.C.
L.L.W.
-3.0m G.S.C.
~90 m
~75 m
AVERAGE BANK LEVEL
-1.0m G.S.C.
3m
5
5
3m
7.6m
1.0m
10m
20m

TRENCH CROSS SECTION ACROSS INTERTIDAL FLATS
CHAINAGE 2 840.00 - 6 420.00


WORKING AREA RESERVE 100m
WORKING AREA RESERVE 100m
H.H.W.
+1.9m G.S.C.
M.S.L.
0.0m G.S.C.
L.L.W.
-3.0m G.S.C.
~60m
~45m
AVERAGE BANK LEVEL
-2.0m G.S.C.
3m
5.6m
1.0m
10m
20m

TRENCH CROSS SECTION ACROSS INTERTIDAL FLATS
CHAINAGE 6 420.00 - 8 550.00


10
0
10
20
30m
SCALE

NOTES

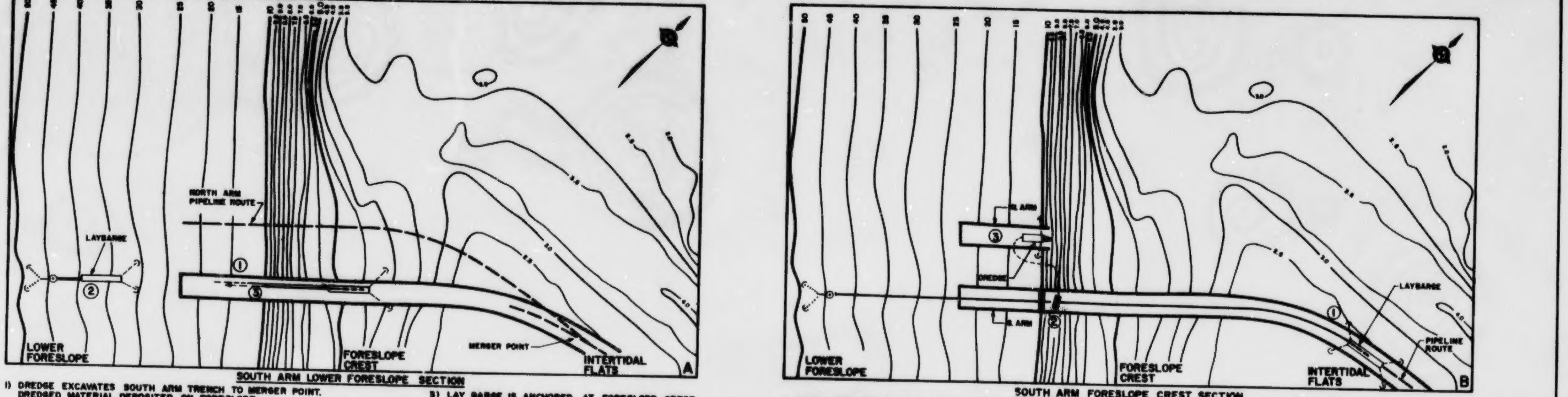
SOLID LINE DENOTES ASSUMED TRENCH PROFILE PRIOR TO PIPELAYING.

DASHED LINE DENOTES DREDGED PROFILE.

FIGURE 3

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT.

TYPICAL TRENCH CROSS SECTIONS
ACROSS INTERTIDAL FLATS
CHAINAGE 2 840.00-8 550.00 METRES



50
45
40
35
30
25
20
15
10
NORTH ARM PIPELINE ROUTE
LAYBARGE
①
②
③
LOWER FORESLOPE
FORESLOPE CREST
MERGER POINT
INTERTIDAL FLATS
A
N. ARM
S. ARM
DREDGE
PIPELINE ROUTE
B

SOUTH ARM LOWER FORESLOPE SECTION

1) DREDGE EXCAVATES SOUTH ARM TRENCH TO MERGER POINT. DREDGED MATERIAL DEPOSITED ON FORESLOPE.

2) SOUTH ARM SHEAVE BLOCK IS POSITIONED AND PULLING WIRES ARE LAID TO FORESLOPE CREST.

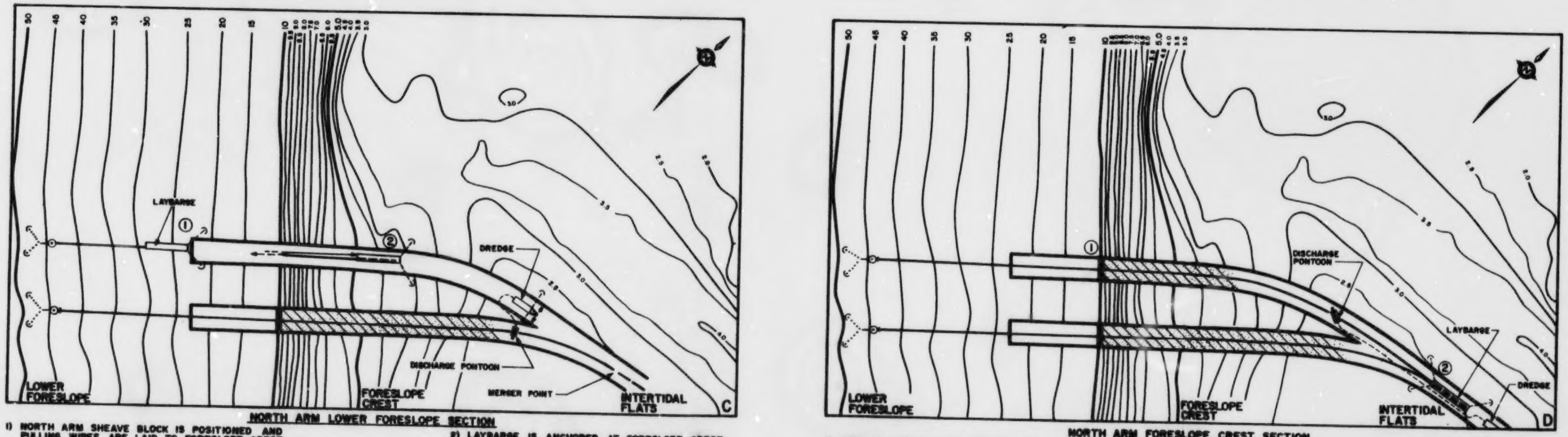
3) LAY BARGE IS ANCHORED AT FORESLOPE CREST AND PIPELINE PULLED OVER STERN UNTIL END REACHES SHEAVE BLOCK.

SOUTH ARM FORESLOPE CREST SECTION

1) SOUTH ARM PIPELINE IS LAID TO MERGER POINT, THEN CAPPED AND LOWERED INTO BOTTOM OF TRENCH.

2) SAND IS DUMPED FROM SCOWS ACROSS SOUTH ARM TO FORM A SEAL.

3) DREDGE EXCAVATES NORTH ARM TRENCH. DREDGED MATERIAL DISCHARGED INTO SOUTH ARM TRENCH.



50
45
40
35
30
25
20
15
10
LAYBARGE
①
②
DREDGE
DISCHARGE PONTOON
MERGER POINT
LOWER FORESLOPE
FORESLOPE CREST
INTERTIDAL FLATS
C
D
SCALE
0 50 100 200 300m

NORTH ARM LOWER FORESLOPE SECTION

1) NORTH ARM SHEAVE BLOCK IS POSITIONED AND PULLING WIRES ARE LAID TO FORESLOPE CREST.

2) LAYBARGE IS ANCHORED AT FORESLOPE CREST AND PIPELINE PULLED OVER STERN UNTIL END REACHES SHEAVE BLOCK.

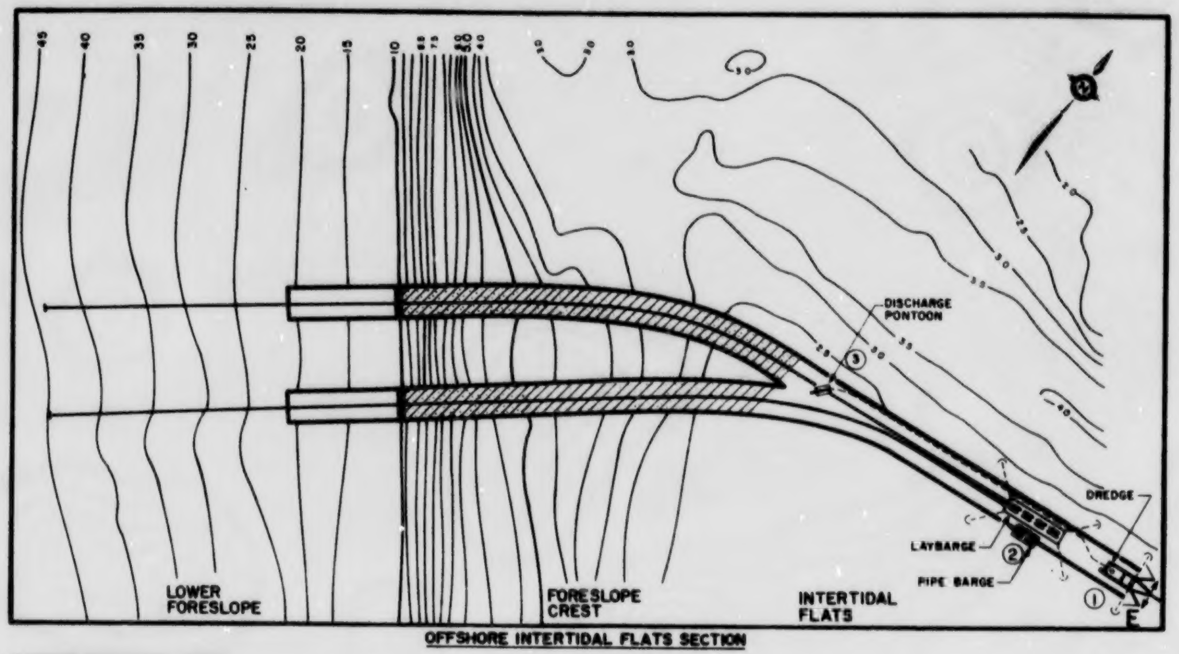
NORTH ARM FORESLOPE CREST SECTION

1) SAND IS DUMPED FROM SCOWS ACROSS NORTH ARM TO FORM A SEAL.

2) NORTH ARM PIPELINE IS LAID TO MERGER POINT. SOUTH ARM PIPELINE IS RAISED AND BOTH LINES ARE PREPARED FOR LAYING ACROSS INTERTIDAL FLATS.

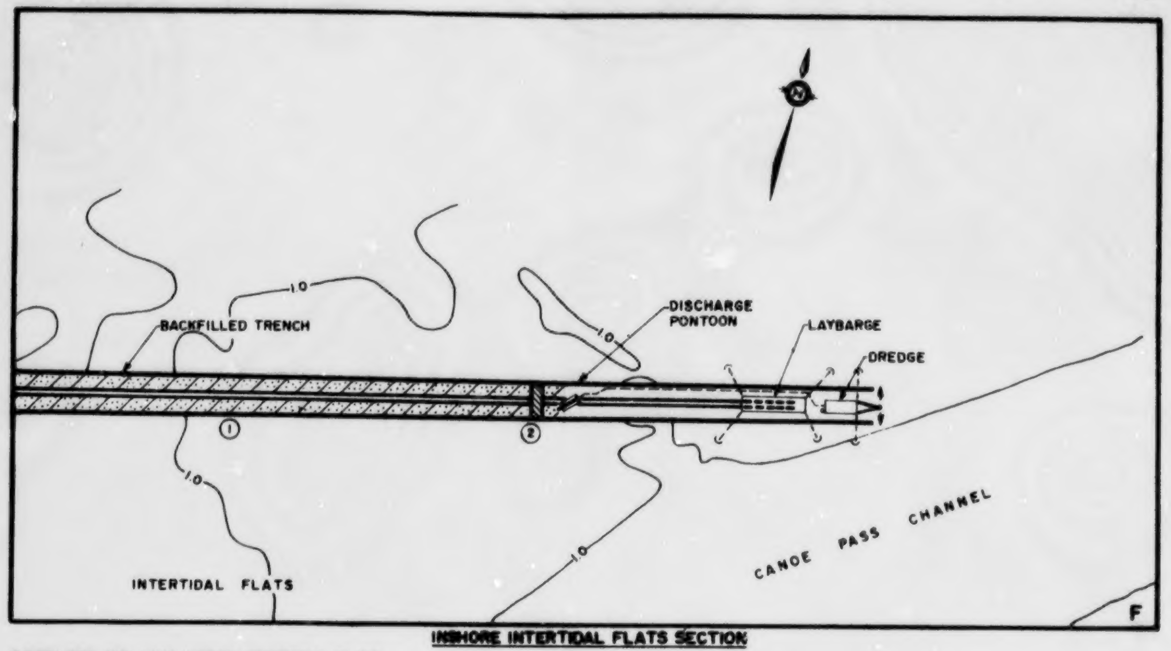
FIGURE 4

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT
LANDWARDS CONSTRUCTION
SEQUENCE OF MARINE OPERATIONS PART I


45
40
35
30
25
20
15
10
LOWER FORESLOPE
FORESLOPE CREST
INTERTIDAL FLATS
DISCHARGE PONTOON
DREDGE
LAYBARGE
PIPE BARGE
①
②
③
E

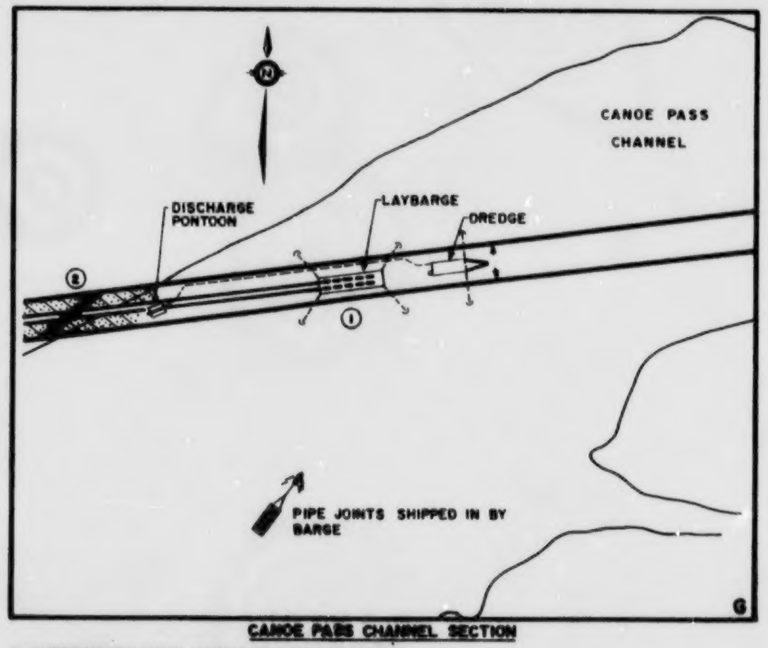
OFFSHORE INTERTIDAL FLATS SECTION

1) DREDGE EXCAVATES TRENCH.
2) LAYBARGE FOLLOWS LAYING TWO PIPELINES.
3) DISCHARGE PONTOON FOLLOWS BEHIND LAYBARGE BACKFILLING THE TRENCH.


BACKFILLED TRENCH
DISCHARGE PONTOON
LAYBARGE
DREDGE
1.0
①
②
INTERTIDAL FLATS
CANOE PASS CHANNEL
F

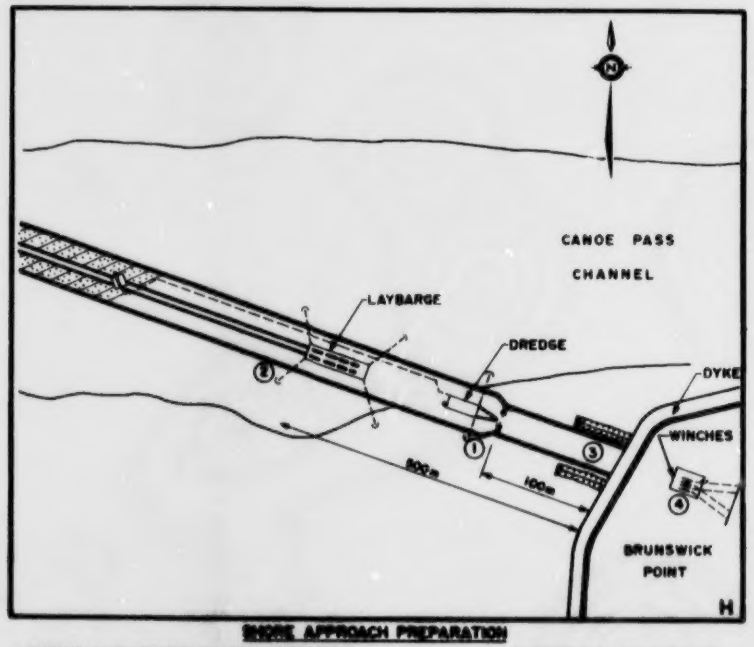
INSHORE INTERTIDAL FLATS SECTION

1) PIPELINES ARE LAID ACROSS INTERTIDAL FLATS.
2) PRIOR TO BREAKING THROUGH CANOE PASS CHANNEL BANK. SAND IS DUMPED FROM SCOWS ACROSS CONSTRUCTION TRENCH TO SEAL IT.


CANOE PASS CHANNEL
DISCHARGE PONTOON
LAYBARGE
DREDGE
②
①
PIPE JOINTS SHIPPED IN BY BARGE
G

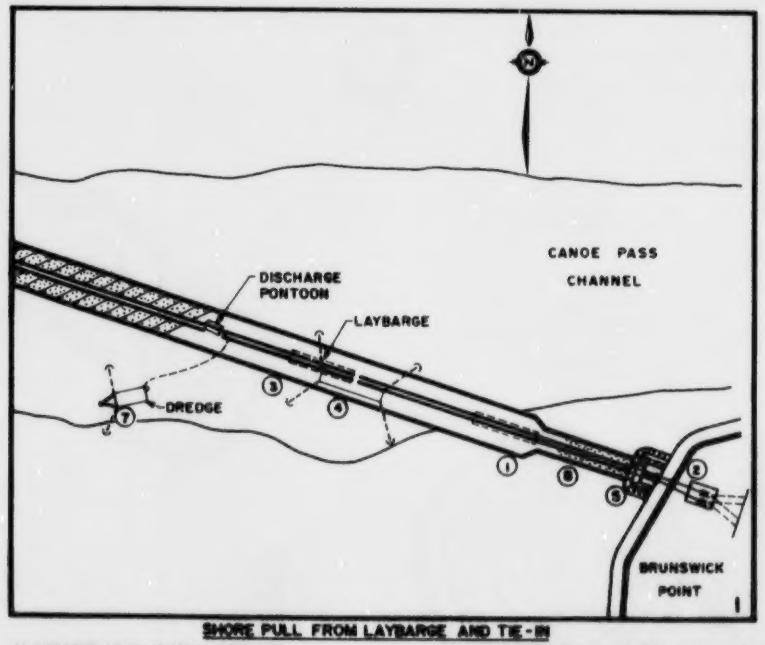
CANOE PASS CHANNEL SECTION

1) CONSTRUCTION TRAIN MOVES INTO CANOE PASS CHANNEL.
2) SAND IS DUMPED FROM SCOWS ACROSS TRENCH TO FORM SECOND SEAL.


CANOE PASS CHANNEL
LAYBARGE
DREDGE
DYKE
WINCHES
②
①
③
④
800m
100m
BRUNSWICK POINT
H

SHORE APPROACH PREPARATION

1) TRENCH IS EXCAVATED TO 100m FROM DYKE.
2) PIPELINES ARE LAID TO WITHIN 800m OF DYKE. THEN CAPPED AND LOWERED INTO TRENCH.
3) SHORE APPROACH TRENCH IS EXCAVATED. MATERIAL IS STOCKPILED EITHER SIDE OF TRENCH.
4) SHORE PULL WINCHES ARE SET UP.


CANOE PASS CHANNEL
DISCHARGE PONTOON
LAYBARGE
DREDGE
⑦
③
④
①
⑥
⑤
②
BRUNSWICK POINT
I

SHORE PULL FROM LAYBARGE AND TIE-IN

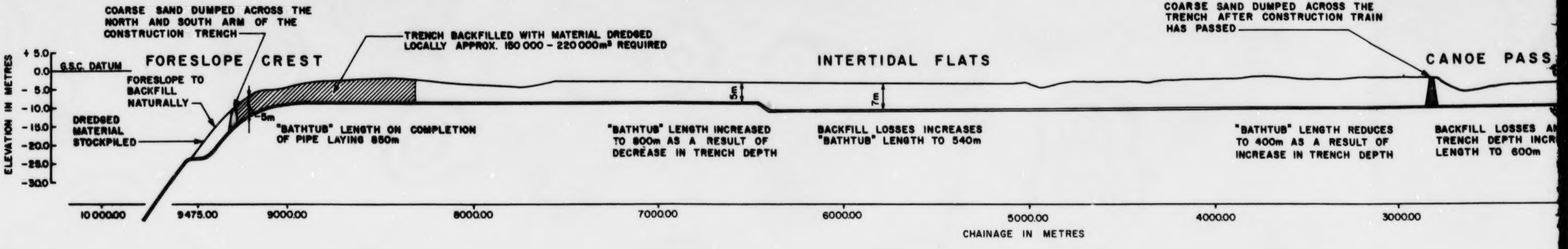
1) LAYBARGE SETS UP 150m OFFSHORE.
2) PIPESTRINGS ARE PULLED ASHORE.
3) LAYBARGE MOVES OFFSHORE AND PIPES ARE LAID TO ENDS OF PIPELINES COMPLETED EARLIER.
4) PIPELINES ARE TIED-IN.
5) COFFERDAM IS CONSTRUCTED AT DYKE (SEE PLATE 5-21) SHORE PULL WINCHES REMOVED AND PIPELINES LAID INSHORE.
6) PIPELINES ARE HYDROSTATICALLY TESTED.
7) TRENCH IS BACKFILLED BY DREDGING SAND FROM LOCAL SAND BANKS.
8) DYKE AND SHORE APPROACH TRENCH ARE BACKFILLED AND COFFERDAM REMOVED.
9) SHEAVE BLOCKS AND ANCHORS ARE RECOVERED AND MARINE EQUIPMENT IS DEMOBILIZED.

SCALE
0 50 100 200 300m

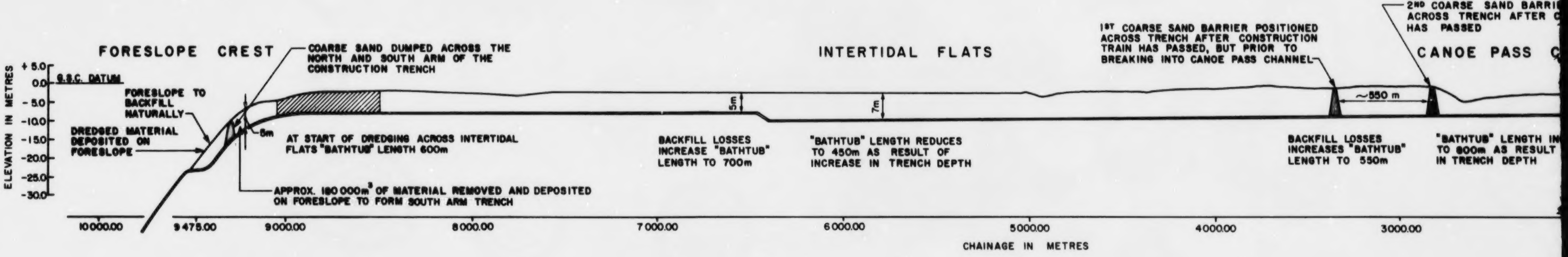
FIGURE 4

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

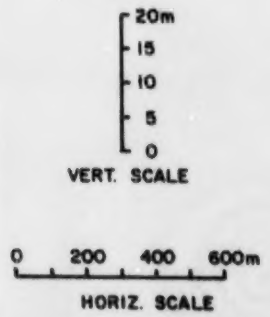
LANDWARDS CONSTRUCTION
SEQUENCE OF MARINE OPERATIONS PART II


COARSE SAND DUMPED ACROSS THE NORTH AND SOUTH ARM OF THE CONSTRUCTION TRENCH
TRENCH BACKFILLED WITH MATERIAL DREDGED LOCALLY APPROX. 180 000 - 220 000m³ REQUIRED
COARSE SAND DUMPED ACROSS THE TRENCH AFTER CONSTRUCTION TRAIN HAS PASSED
ELEVATION IN METRES
+ 5.0
0.0
- 5.0
-10.0
-15.0
-20.0
-25.0
-30.0
G.S.C. DATUM
FORESLOPE CREST
INTERTIDAL FLATS
CANOE PASS
FORESLOPE TO BACKFILL NATURALLY
DREDGED MATERIAL STOCKPILED
5m
5m
7m
"BATHTUB" LENGTH ON COMPLETION OF PIPE LAYING 850m
"BATHTUB" LENGTH INCREASED TO 800m AS A RESULT OF DECREASE IN TRENCH DEPTH
BACKFILL LOSSES INCREASES "BATHTUB" LENGTH TO 540m
"BATHTUB" LENGTH REDUCES TO 400m AS A RESULT OF INCREASE IN TRENCH DEPTH
BACKFILL LOSSES AN TRENCH DEPTH INCR LENGTH TO 600m
10 000.00
9 475.00
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
CHAINAGE IN METRES

SEAWARDS CONSTRUCTION


FORESLOPE CREST
COARSE SAND DUMPED ACROSS THE NORTH AND SOUTH ARM OF THE CONSTRUCTION TRENCH
INTERTIDAL FLATS
1ST COARSE SAND BARRIER POSITIONED ACROSS TRENCH AFTER CONSTRUCTION TRAIN HAS PASSED, BUT PRIOR TO BREAKING INTO CANOE PASS CHANNEL
2ND COARSE SAND BARRI ACROSS TRENCH AFTER C HAS PASSED
CANOE PASS C
ELEVATION IN METRES
+ 5.0
0.0
- 5.0
-10.0
-15.0
-20.0
-25.0
-30.0
G.S.C. DATUM
FORESLOPE TO BACKFILL NATURALLY
DREDGED MATERIAL DEPOSITED ON FORESLOPE
5m
5m
7m
~550 m
AT START OF DREDGING ACROSS INTERTIDAL FLATS "BATHTUB" LENGTH 600m
APPROX. 180 000m³ OF MATERIAL REMOVED AND DEPOSITED ON FORESLOPE TO FORM SOUTH ARM TRENCH
BACKFILL LOSSES INCREASE "BATHTUB" LENGTH TO 700m
"BATHTUB" LENGTH REDUCES TO 450m AS RESULT OF INCREASE IN TRENCH DEPTH
BACKFILL LOSSES INCREASES "BATHTUB" LENGTH TO 550m
"BATHTUB" LENGTH IN TO 800m AS RESULT IN TRENCH DEPTH
10 000.00
9 475.00
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
CHAINAGE IN METRES

LANDWARDS CONSTRUCTION


20m
15
10
5
0
VERT. SCALE
0
200
400
600m
HORIZ. SCALE

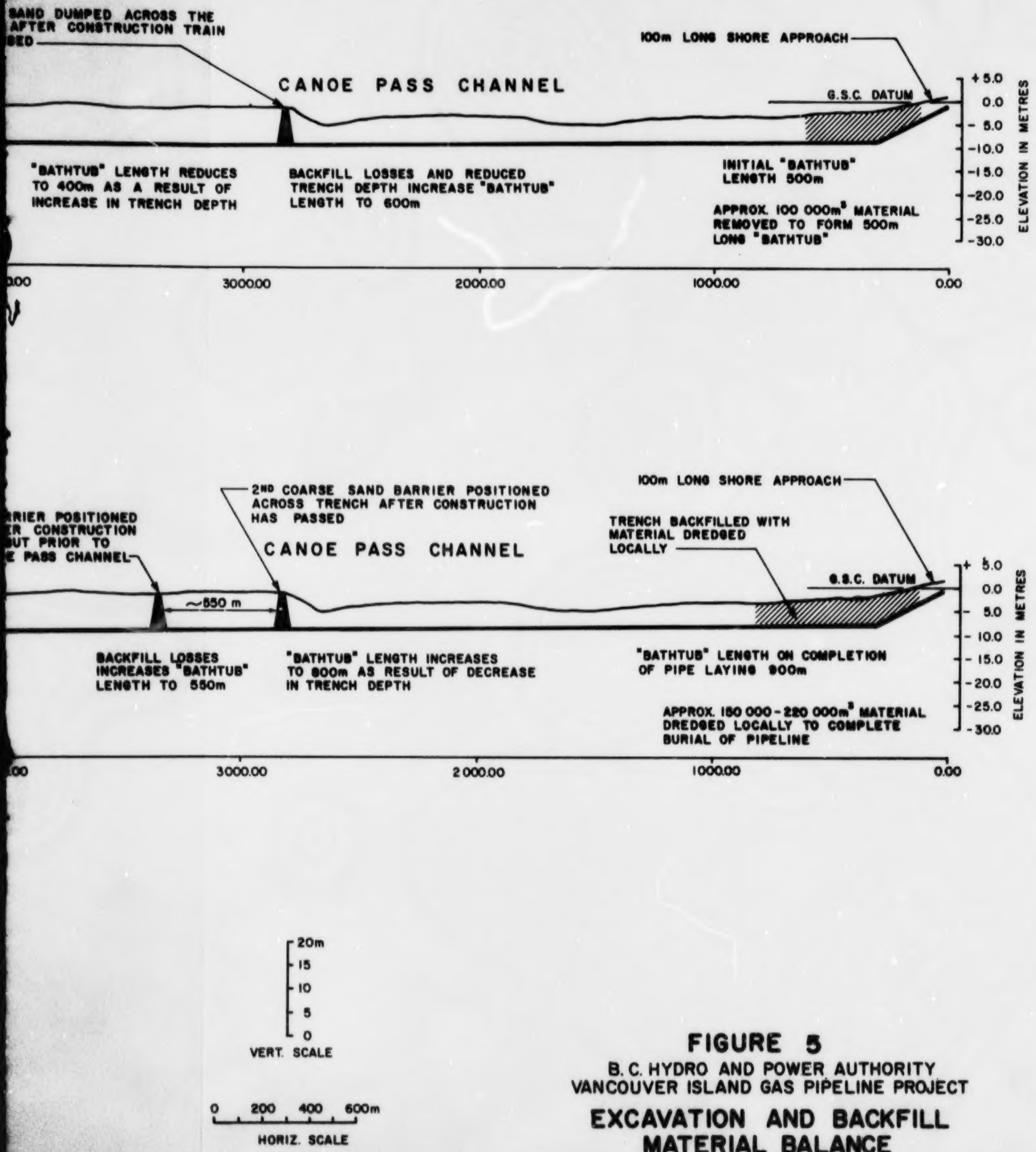
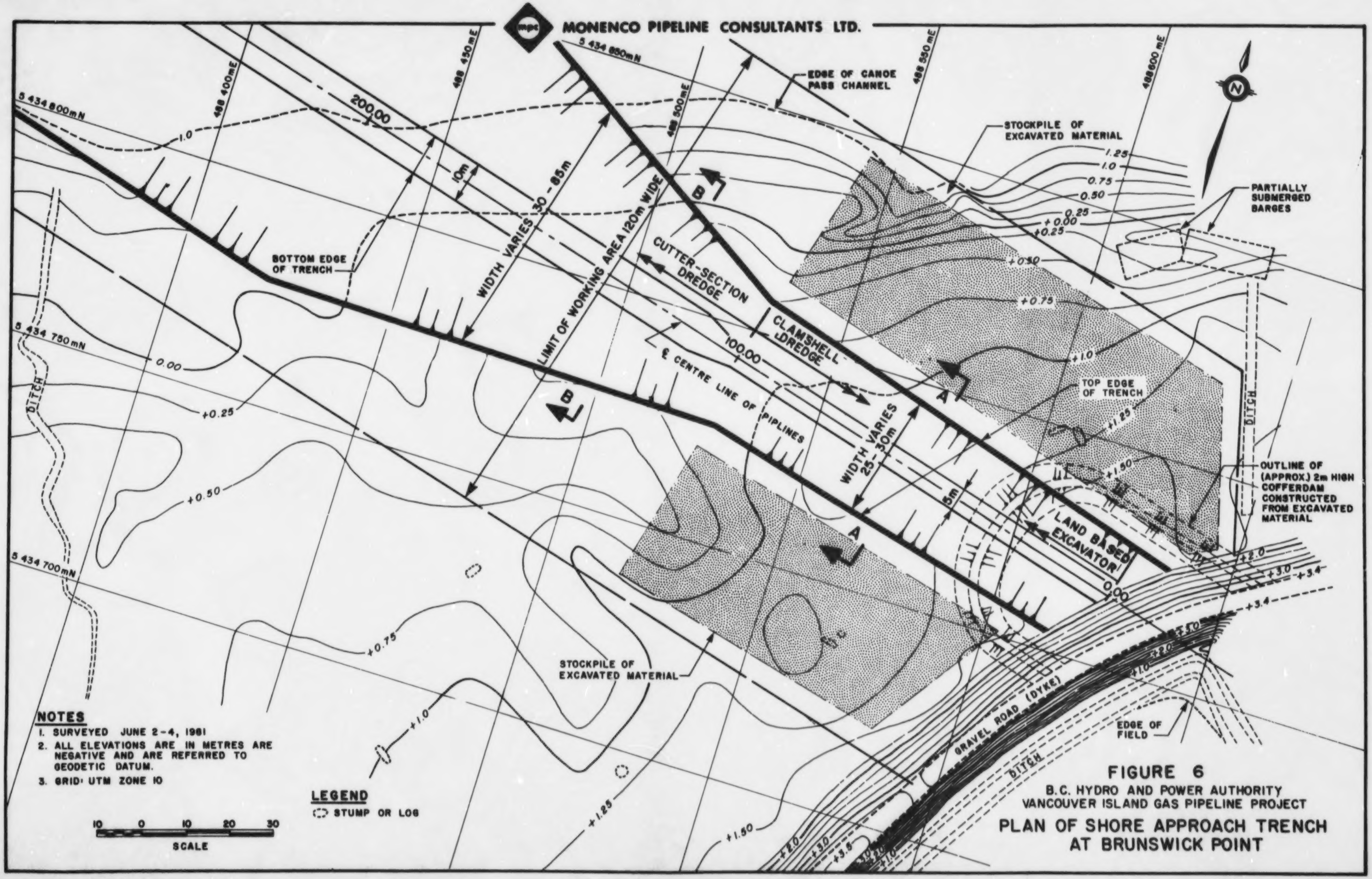

SAND DUMPED ACROSS THE
AFTER CONSTRUCTION TRAIN
SED
CANOE PASS CHANNEL
100m LONG SHORE APPROACH
G.S.C. DATUM
"BATHTUB" LENGTH REDUCES TO 400m AS A RESULT OF INCREASE IN TRENCH DEPTH
BACKFILL LOSSES AND REDUCED TRENCH DEPTH INCREASE "BATHTUB" LENGTH TO 600m
INITIAL "BATHTUB" LENGTH 500m
APPROX. 100 000m³ MATERIAL REMOVED TO FORM 500m LONG "BATHTUB"
+5.0
0.0
- 5.0
-10.0
-15.0
-20.0
-25.0
-30.0
ELEVATION IN METRES
.00
3000.00
2000.00
1000.00
0.00
2ND COARSE SAND BARRIER POSITIONED ACROSS TRENCH AFTER CONSTRUCTION HAS PASSED
RIER POSITIONED
ER CONSTRUCTION
UT PRIOR TO
E PASS CHANNEL
CANOE PASS CHANNEL
~550 m
100m LONG SHORE APPROACH
TRENCH BACKFILLED WITH MATERIAL DREDGED LOCALLY
G.S.C. DATUM
BACKFILL LOSSES INCREASES "BATHTUB" LENGTH TO 550m
"BATHTUB" LENGTH INCREASES TO 800m AS RESULT OF DECREASE IN TRENCH DEPTH
"BATHTUB" LENGTH ON COMPLETION OF PIPE LAYING 900m
APPROX. 150 000 - 220 000m³ MATERIAL DREDGED LOCALLY TO COMPLETE BURIAL OF PIPELINE
+ 5.0
0.0
- 5.0
- 10.0
- 15.0
- 20.0
- 25.0
- 30.0
ELEVATION IN METRES
.00
3000.00
2000.00
1000.00
0.00
20m
15
10
5
0
VERT. SCALE
0
200
400
600m
HORIZ. SCALE

FIGURE 5

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

EXCAVATION AND BACKFILL MATERIAL BALANCE


MONENCO PIPELINE CONSULTANTS LTD.
5 434 850mN
5 434 800mN
5 434 750mN
5 434 700mN
488 400mE
488 450mE
488 500mE
488 550mE
488 600mE
EDGE OF CANOE PASS CHANNEL
STOCKPILE OF EXCAVATED MATERIAL
PARTIALLY SUBMERGED BARGES
200.00
100.00
10m
5m
WIDTH VARIES 30 - 85m
LIMIT OF WORKING AREA 120m WIDE
CUTTER-SECTION DREDGE
CLAMSHELL DREDGE
℄ CENTRE LINE OF PIPLINES
WIDTH VARIES 25 - 30m
LAND BASED EXCAVATOR
BOTTOM EDGE OF TRENCH
TOP EDGE OF TRENCH
OUTLINE OF (APPROX.) 2m HIGH COFFERDAM CONSTRUCTED FROM EXCAVATED MATERIAL
STOCKPILE OF EXCAVATED MATERIAL
GRAVEL ROAD (DYKE)
DITCH
EDGE OF FIELD
A
B
1.0
1.25
0.75
0.50
0.25
+0.00
+0.25
+0.50
+0.75
+1.0
+1.25
+1.50
0.00
+2.0
+3.0
+3.4
+3.5
N
10 0 10 20 30
SCALE

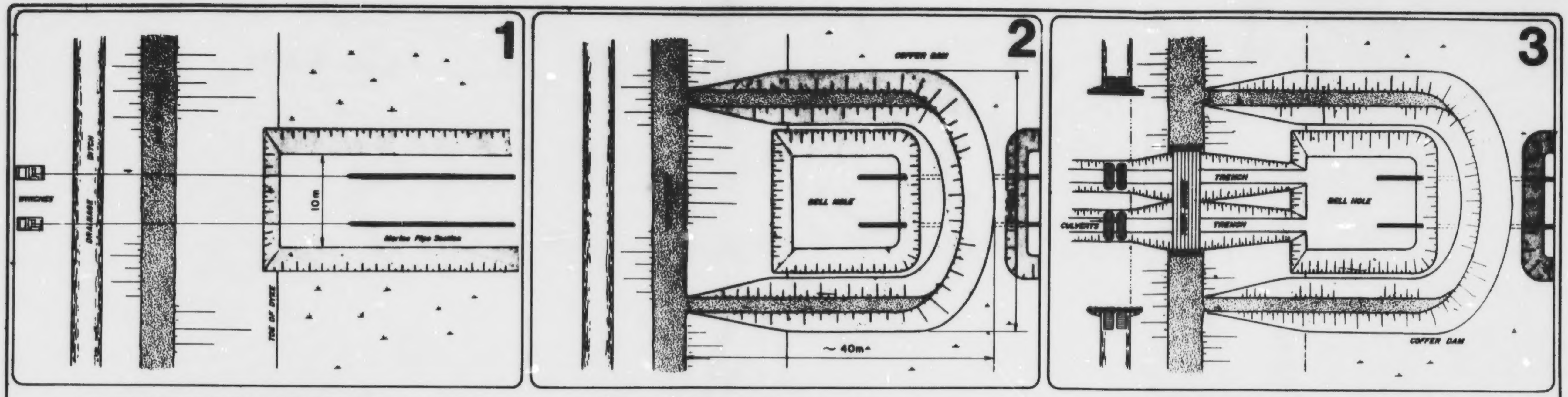
NOTES

1. SURVEYED JUNE 2-4, 1981
2. ALL ELEVATIONS ARE IN METRES ARE NEGATIVE AND ARE REFERRED TO GEODETIC DATUM.
3. GRID: UTM ZONE 10

LEGEND

⬭ STUMP OR LOG

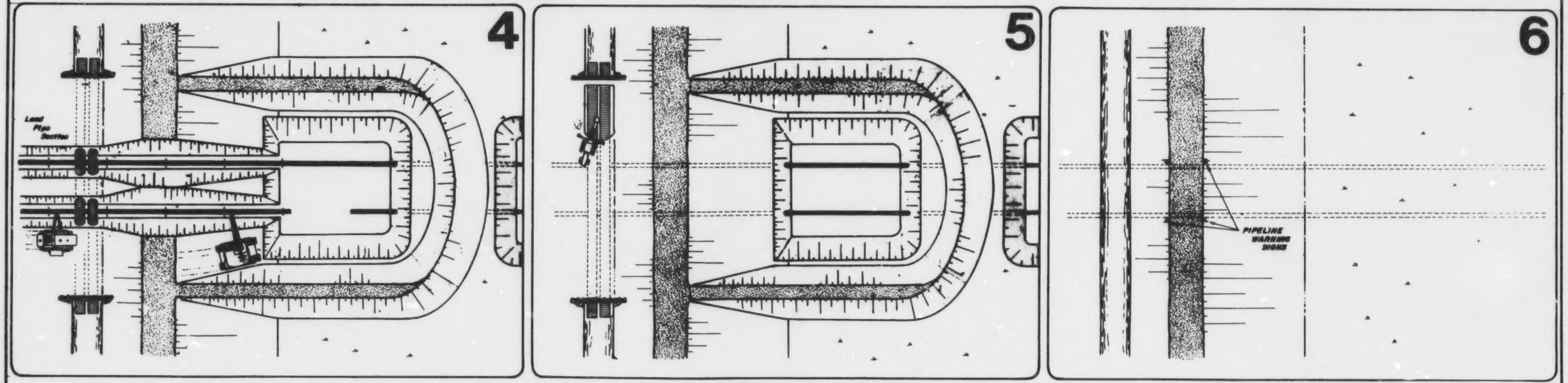
FIGURE 6
B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT
PLAN OF SHORE APPROACH TRENCH
AT BRUNSWICK POINT


1
WINCHES
DRAINAGE DITCH
TOE OF DYKE
10m
Marine Pipe Section
2
COFFER DAM
BELL HOLE
~40m
3
TRENCH
BELL HOLE
TRENCH
CULVERTS
COFFER DAM

A 10m WIDE TRENCH IS EXCAVATED UP TO THE TOE OF THE DYKE. THE MARINE PIPES ARE PULLED ASHORE FROM THE LAYBARGE AND RESTED AS SHOWN IN SEQUENCE 1.

A 40m x 30m COFFER DAM IS CONSTRUCTED TO PREVENT THE SEA WATER ENTERING THE TRENCH DURING THE CUTTING THROUGH OF THE DYKE AND DURING THE HYDROSTATIC TEST.

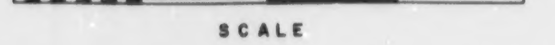
TWO TRENCHES FOR THE LAND LINE ARE CUT THROUGH THE DYKE EXTENDING INTO THE BELL HOLE. THE FUNCTION OF THE DRAINAGE DITCH INSIDE THE DYKE IS MAINTAINED BY CULVERTS.


4
Land Pipe Section
5
6
PIPELINE WARNING SIGNS

DOUBLE JOINTS OF PIPE ARE LIFTED INTO THE TRENCHES AND WELDED ONTO THE MARINE SECTION OF THE PIPELINE UNTIL THEY EXTEND INSHORE TO THE START OF THE LANDLINE SECTION. THE TWO PIPELINES ARE HYDROSTATICALLY TESTED.

BOTH TRENCHES ARE BACKFILLED RESTORING THE DYKE TO ITS ORIGINAL PROFILE. THE CULVERTING IS REMOVED AND THE DRAINAGE DITCH IS RESTORED AS BEFORE.

THE COFFER DAM IS REMOVED, THE BELLHOLE IS BACKFILLED AND THE DYKE IS RESTORED TO ITS ORIGINAL CONDITION. THE BACKFILLING OF THE SHORE APPROACH TRENCH IS COMPLETED AND THE LAND BASED EQUIPMENT DEMOBILIZED. PIPELINE WARNINGS SIGNS ARE THEN ERECTED.


10
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30m

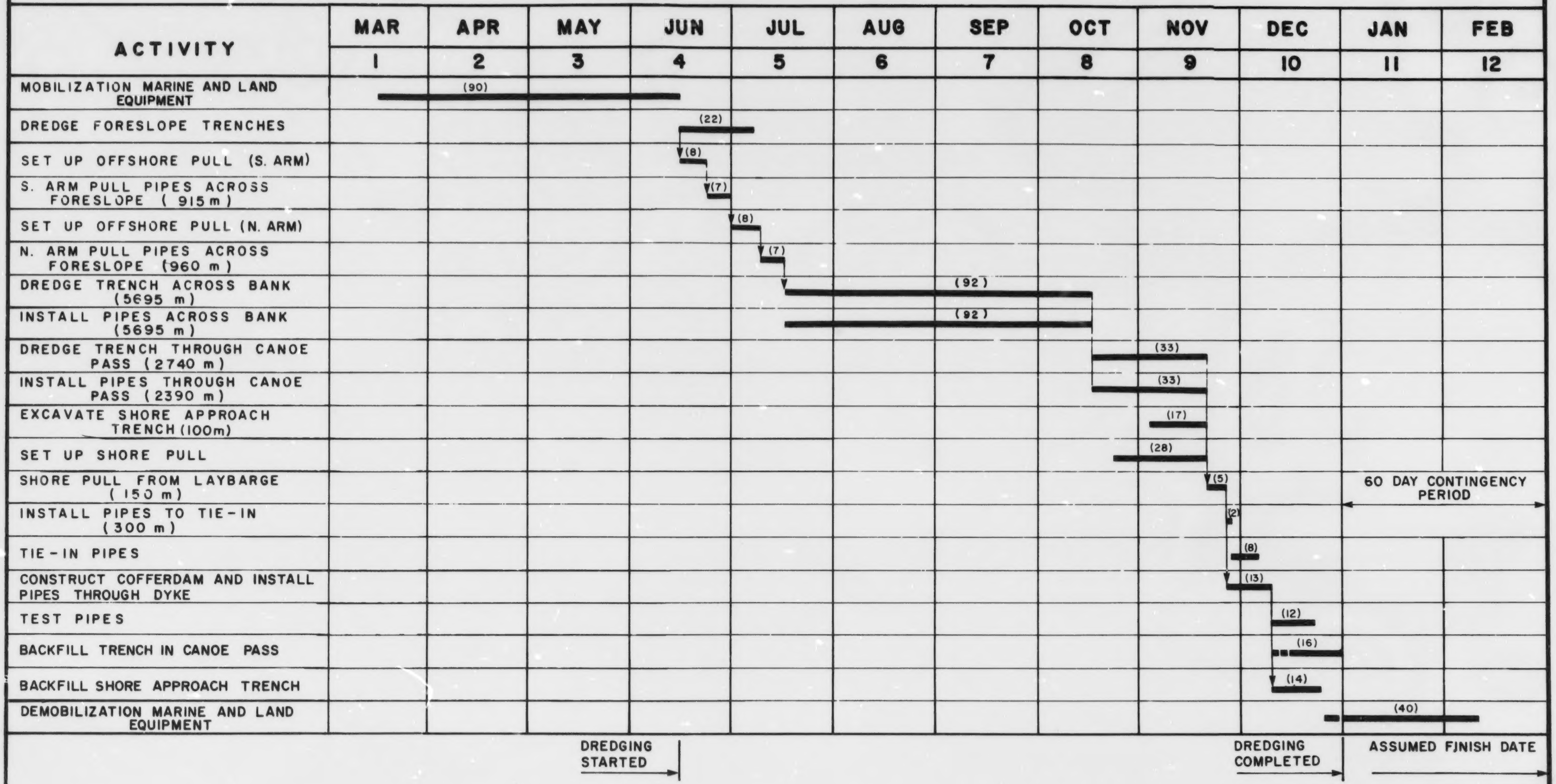
SCALE

FIGURE 7

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

SEQUENCE OF OPERATIONS FOR CROSSING DYKE

MONENCO PIPELINE CONSULTANTS LTD.



( ) NUMBER OF CALENDAR DAY

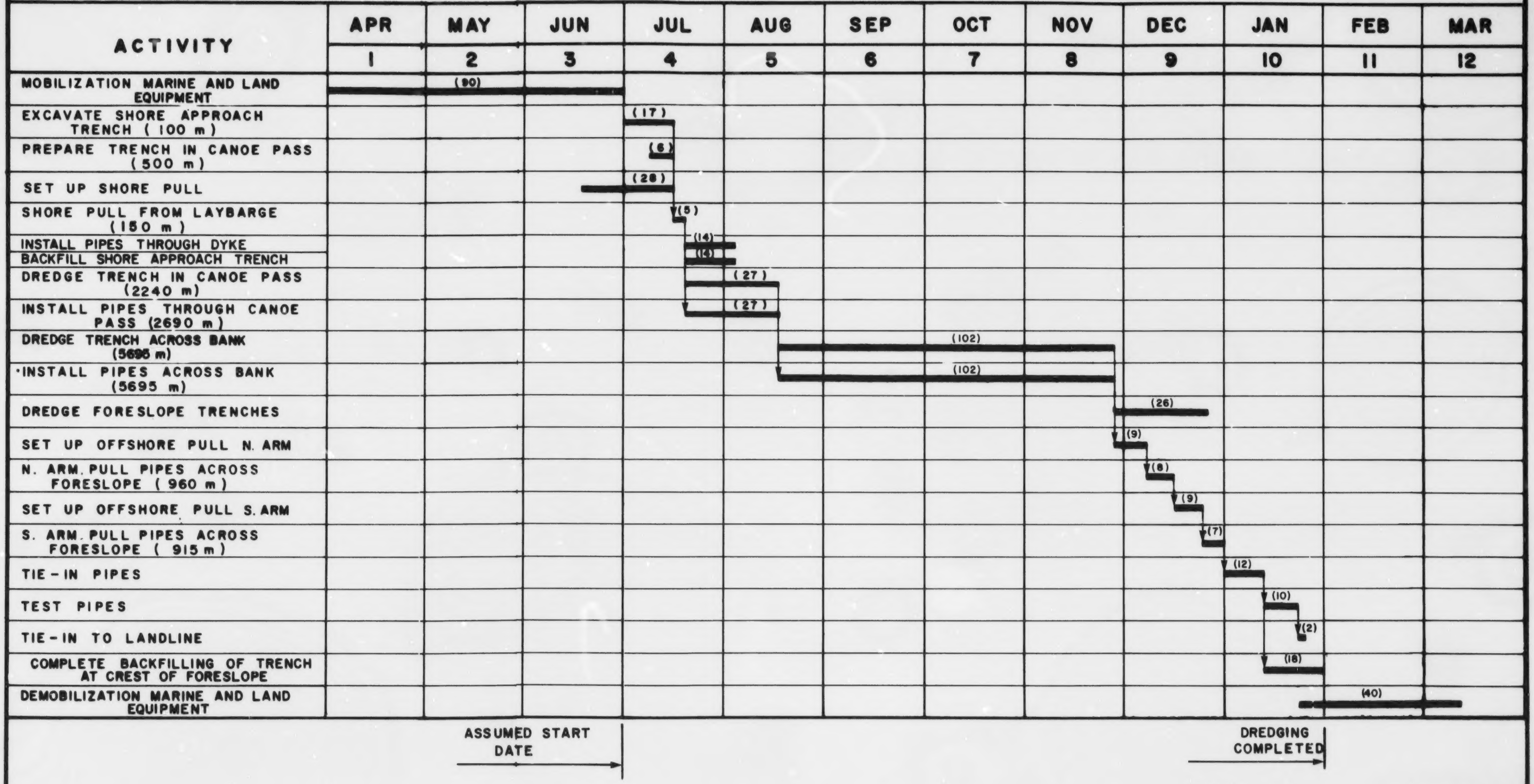
FIGURE 8

B.C. HYDRO AND POWER AUTHORITY

VANCOUVER ISLAND GAS PIPELINE PROJECT

LANDWARDS CONSTRUCTION SCHEDULE

MONENCO PIPELINE CONSULTANTS LTD.



( ) NUMBER OF CALENDAR DAY

FIGURE 9

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

SEAWARDS CONSTRUCTION SCHEDULE

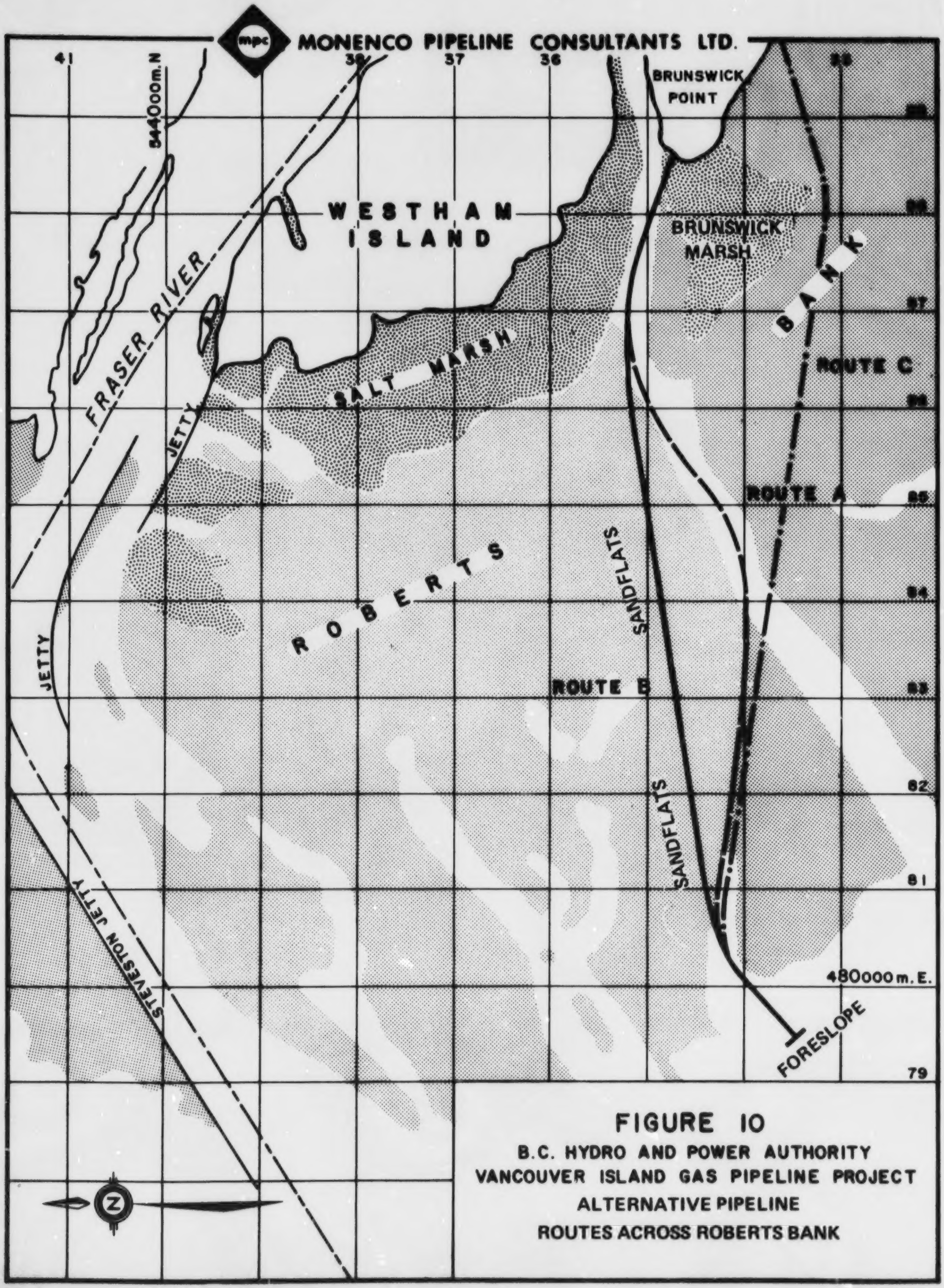

MONENCO PIPELINE CONSULTANTS LTD.
mpc
41
38
37
36
33
544000m.N
BRUNSWICK POINT
WESTHAM ISLAND
BRUNSWICK MARSH
FRASER RIVER
SALT MARSH
BANK
ROUTE C
87
ROUTE A
85
JETTY
ROBERTS
SANDFLATS
84
ROUTE B
83
JETTY
82
SANDFLATS
81
STEVESTON JETTY
480000 m. E.
FORESLOPE
79
Z

FIGURE 10

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT
ALTERNATIVE PIPELINE
ROUTES ACROSS ROBERTS BANK

Westham Island and Brunswick Marshes

FIGURE 1 1

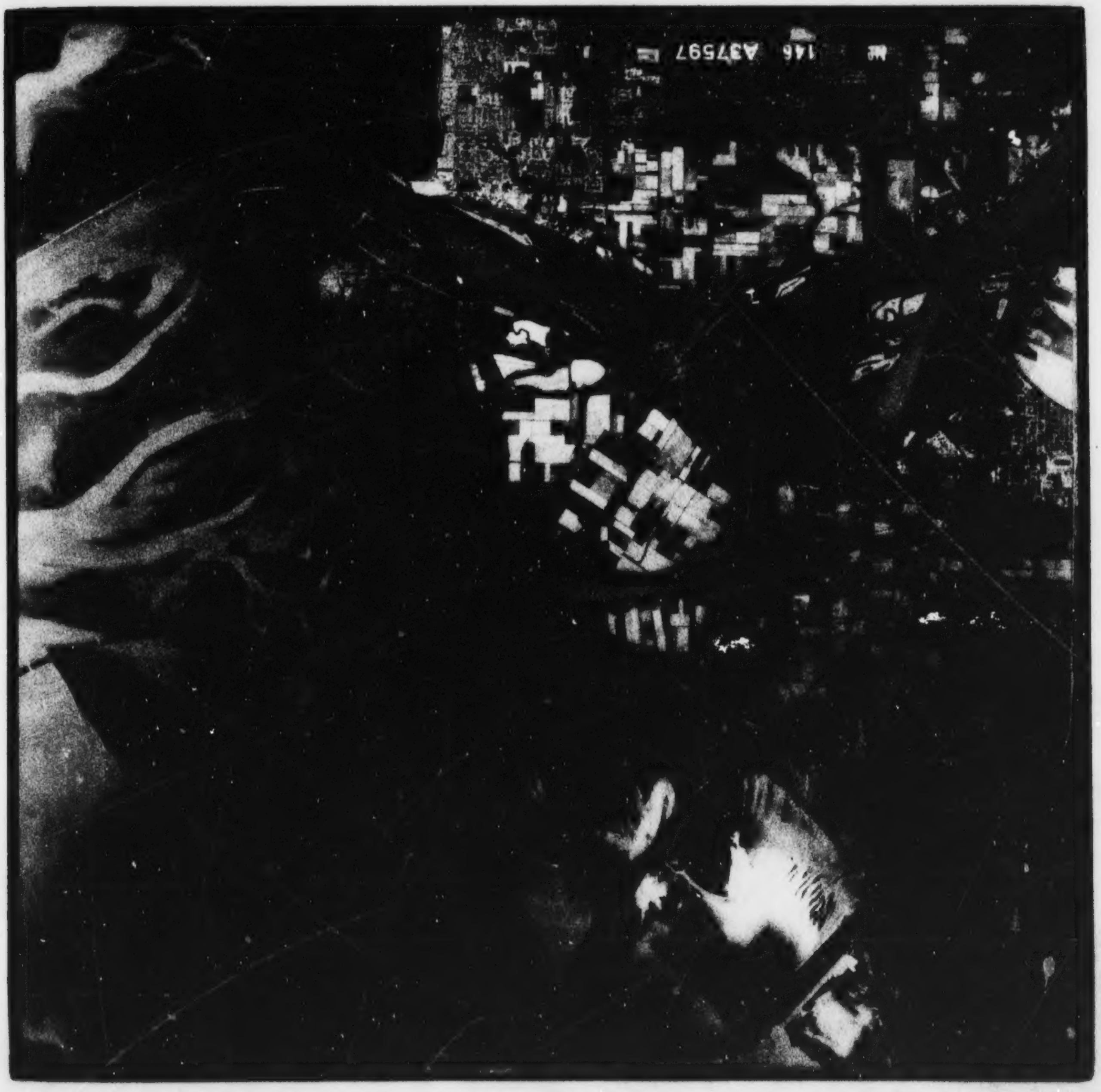
▨ Marsh Area

- - - Proposed Pipeline Route

0 1 2km

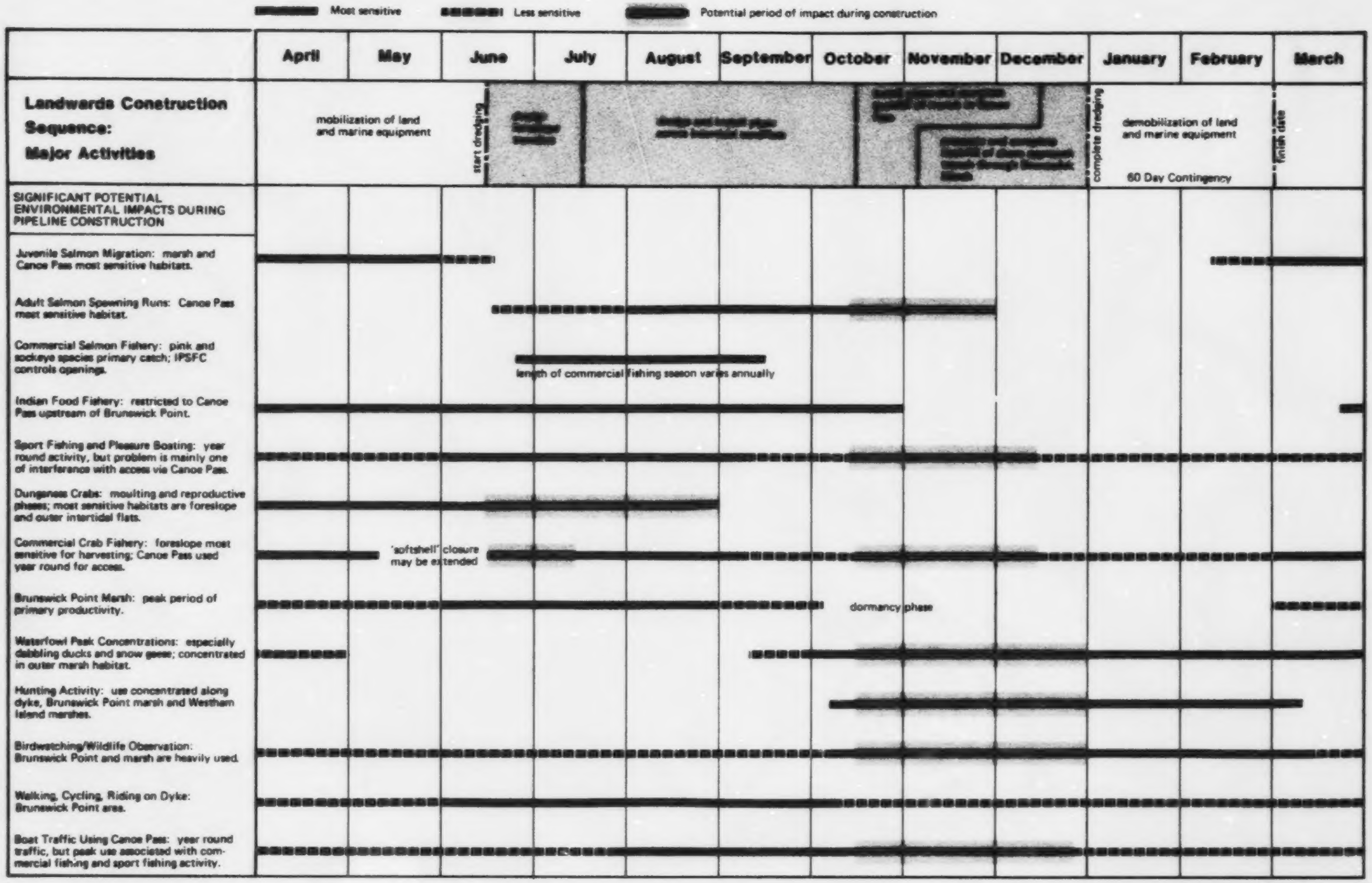
0 1 2 Miles

Scale 1:72,000



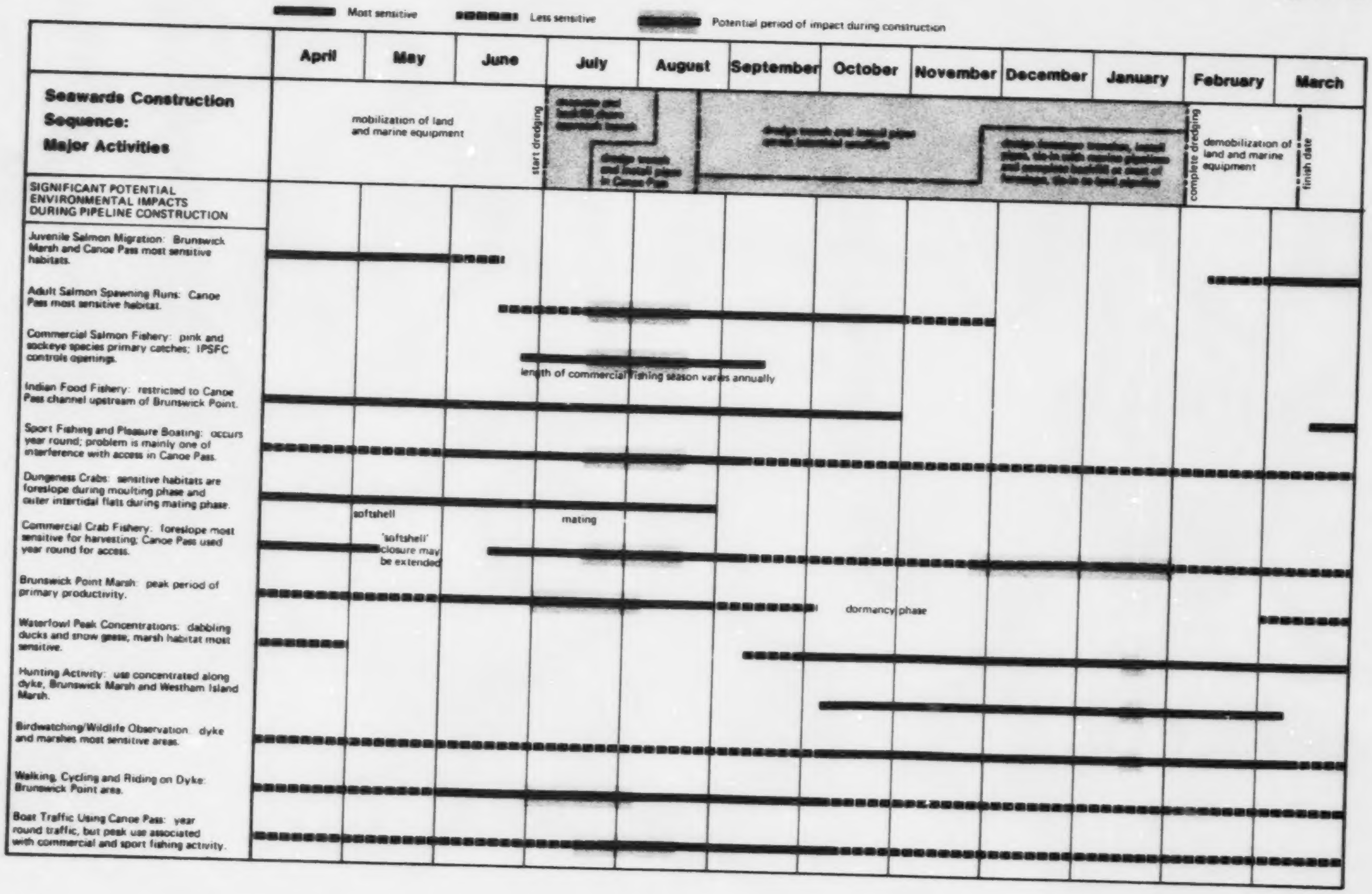
Potential Environmental Impacts Associated with Landwards Sequence

Figure 12



Potential Environmental Impacts Associated with Seawards Sequence

Figure 13



APPENDICES

808

APPROVED AND ORDERED 17 MAR 1977

Lieutenant-Governor

EXECUTIVE COUNCIL CHAMBERS, VICTORIA 17 MAR 1977

Pursuant to the ENVIRONMENT AND LAND USE Act, and upon the recommendation of the undersigned, the Lieutenant-Governor, by and with the advice and consent of the Executive Council, orders that

WHEREAS the Fraser River Estuary and adjacent submerged lands including Boundary and Semiahmoo Bays possess natural environmental significance to British Columbians

AND WHEREAS the Province of British Columbia recognizes the significance of the commercial and sports fisheries, wildlife, recreational and aesthetic values associated with this Estuary,

PURSUANT to the recommendation of the Environment and Land Use Committee every proposed development on the foreshores and land covered by water, more particularly shown outlined and hatched in green on the attached map; lying generally outside the dyking system and known generally as Sturgeon and Roberts Banks and Boundary and Semiahmoo Bays, be subject to a mandatory environmental impact assessment prepared by the proponent

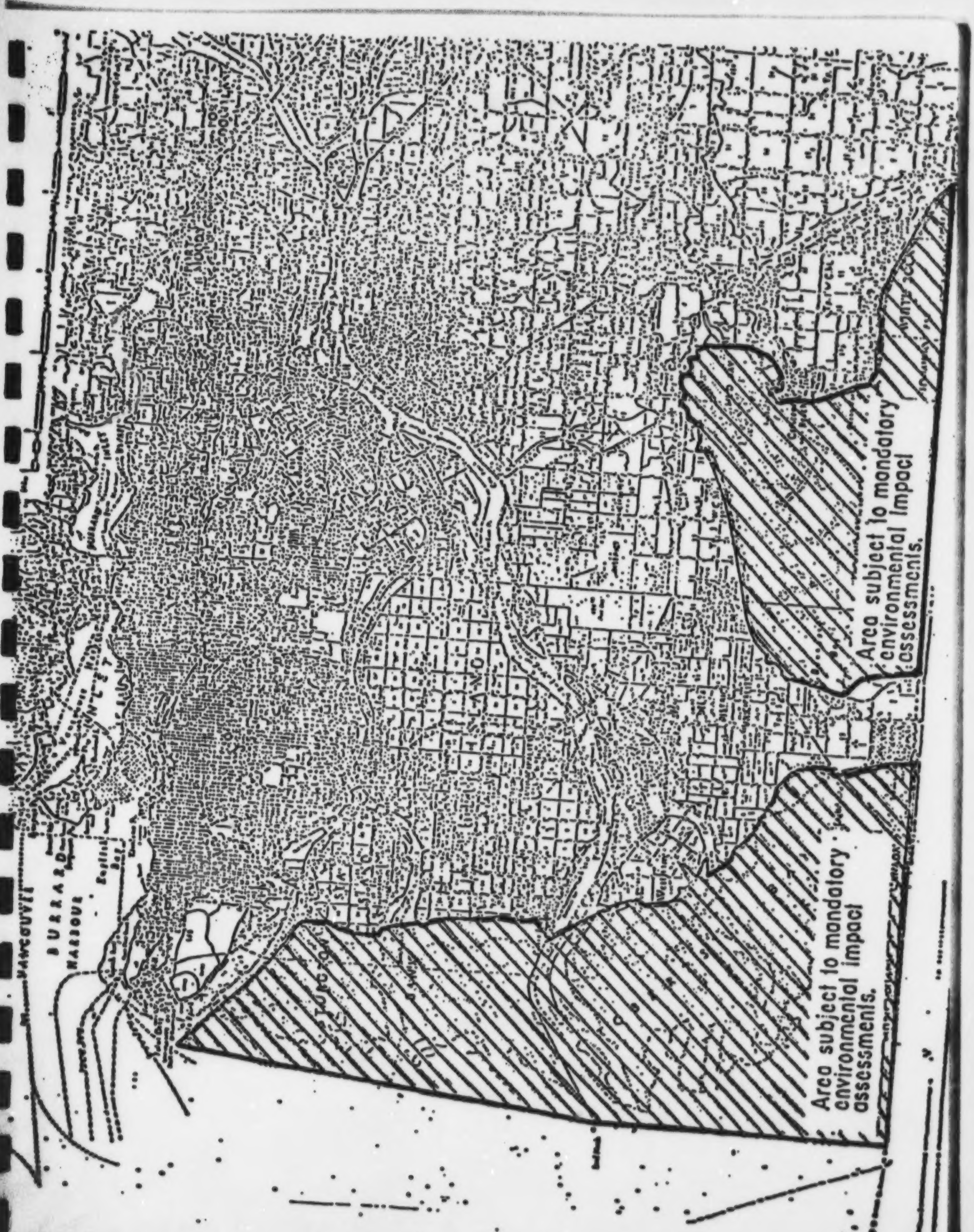
AND THAT no person shall,-

(a) approve a subdivision of land
(b) issue a building permit
(c) issue a lease on Crown Provincial lands
(d) issue a pollution control or sewage disposal permit
(e) approve a land use contract
(f) undertake any new or further construction, alteration, extension or renovation of any building or structure
(g) undertake any dredging or filling of land,

until the environmental impact assessment is reviewed and approved in writing by the Minister of Environment, subject to such terms and conditions as he may prescribe.

Minister of Environment

W. R. Bennett
Presiding Member of the Executive Council


Area subject to mandatory environmental impact assessments.
Area subject to mandatory environmental impact assessments.
VANCOUVER
BURRARD
INLET
HARBOUR
English Bay

TERMS OF REFERENCE: Prepared by
OIC 908 Environmental Assessment Committee

The Environmental Impact Assessment report is to provide a comprehensive identification of physical, biological and resource use impacts which can be expected as a result of constructing a natural gas pipeline system along the proposed route crossing Roberts Bank. The reliability of impact predictions also is to be discussed in the report. The report is to recommend feasible and effective measures for avoiding and mitigating predicted impacts. Any residual or temporal impacts that cannot be avoided or mitigated are to be identified in the report. Both beneficial impacts and adverse impacts are to be identified and enhancement of beneficial impacts as well as mitigation of adverse impacts are to be proposed in the report. The report should include a statement of commitment by B. C. Hydro Gas Division indicating the extent to which the findings and recommendations contained in the report are accepted, if any independent consultant is contracted to prepare the report.

Without compromising accuracy, discussion in the report is to be presented as clearly and succinctly as possible. All discussion in the text of the report should avoid the use of indefinite wording or overly qualified statements as much as possible. Discussion is to be limited to only that which is pertinent to assessment of the proposed project's environmental impacts. Uses of assumptions and speculation should be identified. Any maps, tables, or other graphics which could aid in clarifying matters discussed in the report should be used.

In order to meet the foregoing requirements, the Environmental Impact Assessment report should address, but not necessarily be limited to, aspects of the proposed project outlined as follows:

A. INTRODUCTION

- A very brief reference to the requirement for the EIA under O/C 908 and to the terms of reference.
- A very brief summary of the need and rationale for a natural gas system to Vancouver Island referring to published reports for details.

B. BACKGROUND

- A very brief summary of the corridor and route nomination process leading to the proposed route and referencing the "Corridor and ..... System" report for details.
- Other background information (such as B. C. Hydro's use of the Linear Development Guidelines process, public information efforts, other studies, etc.) can be included as deemed appropriate.

C. STUDY AREA

- Identification of the area examined by the EIA and a brief description of the area's resources and resource use features.
- For the purposes of this EIA, the study area should include Roberts Bank from the Steveston North Jetty south to the Robert Banks Port, bounded on the east generally by the dykes and on the west by the seaward edge (toe) of the Fraser River delta foreslope.

D. PROJECT DESCRIPTION

- Description of the pipeline route as presently proposed. This should include indication of the right-of-way reserve required, the extent of possible deviations in specific alignment and the site(s) being considered for breaching the dyke to gain access to Roberts Bank.

- Description of pipeline construction methods as presently proposed. This should include discussion of the size of pipeline(s), dimensions of the excavations, the depth of cover over the pipeline once laid, an estimate of sediment lost from dredge to dredgate disposal, methods for servicing construction equipment, size of work crew and duration of daily work period, and the time required for construction. Discussion also should explain the alternatives for the starting point and for commencement dates in relation to logistical complications associated with each alternative.
- Description of activities which will and potentially could be involved in maintenance of the pipelines across Roberts Bank.

E. RELEVANT STUDIES UNDERTAKEN

- Description of the geotechnical studies undertaken in the late summer, 1980 and the results of those studies.
- Description of any analyses conducted of existing fisheries data obtained from various sources.
- Description of the results of a study conducted by Dr. C. D. Levings concerning recolonization of benthos following construction of submarine electrical cables at Brunswick Point.
- Other relevant studies relating to vegetation, waterfowl use, fisheries and hunting activities, hydraulic processes, seismic and geological features, etc.
- An explanation of the implications the findings of the above studies have in relation to pipeline alignment and construction should be provided.

F. ASSSESSMENT OF IMPACTS

- Identification and discussion of anticipated physical, biological and resource use impacts associated with pipeline construction, including alignment and construction alternatives. Those impacts that would be temporal in nature should be identified as such and expected durations of impact provided. Any residual or persisting impacts also should be identified.

- Description of impacts should be related to the following resource and resource use features:

1. Substrate composition and morphology.
2. Hydrology, fluvial and oceanographic currents, wind, waves Canoe Pass channel stability.
3. Salinity, suspended sediment, water quality.
4. Vegetation, marsh and algae, community composition and distribution.
5. Benthos, epifauna and meiofauna, community composition and distribution.
6. Fish use (all species), adult and juvenile, including crabs.
7. Waterfowl use and other wildlife species.
8. Commercial, recreational and public use.

G. MEASURES FOR AVOIDING AND MITIGATING IMPACTS

- Proposals for avoiding or mitigating impacts of pipeline construction by route alignment, construction methods, timing of construction period, etc.
- The following aspects should be specifically addressed:

1. Construction timing "window".
2. Construction start-up point and associated methodology.
3. Revegetation of disturbed marsh areas.
4. Dyke closure.
5. Disposal of excess dredgate.
6. Monitoring.

H. CONCLUSIONS

- A summary of the findings of the EIA.

I. RECOMMENDATIONS

- A summary of recommendations concerning pipeline alignment, construction methodology, construction timing, mitigaton measures and so on.
- A description of the proposed project as a function of changes related to the EIA.

J. B. C. HYDRO GAS DIVISION STATEMENT (as applicable)

- Statement concerning the degree to which the proponent accepts the findings and recommendations of the EIA.

1981-02-17

APPENDIX 3

A SHORT TERM STUDY ON THE PRESENCE OF FISH AND DUNGENESS CRABS AT CANOE PASS, ROBERTS BANK

July 22 - August 27, 1982

Prepared by
Fisheries and Oceans Canada 1983

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INTRODUCTION

B.C. Hydro proposes to construct a natural gas pipeline to Vancouver Island which would involve dredging and burial of a dual underwater pipeline 324 mm in diameter. A trench up to 5 metres deep will be dug through the Canoe Pass channel on Roberts Bank. Preliminary design details indicate that dredging should begin sometime in July or early August in order to complete the dredging on schedule and avoid potential weather related down time. To better understand the potential for impact on the fisheries resource, a survey was conducted at Canoe Pass to determine the presence of fish and Dungeness crabs (Cancer magister) from mid-July to the end of August. Sampling began on July 22 and continued until August 27, taking place at 5 sites as indicated in Figure 1.

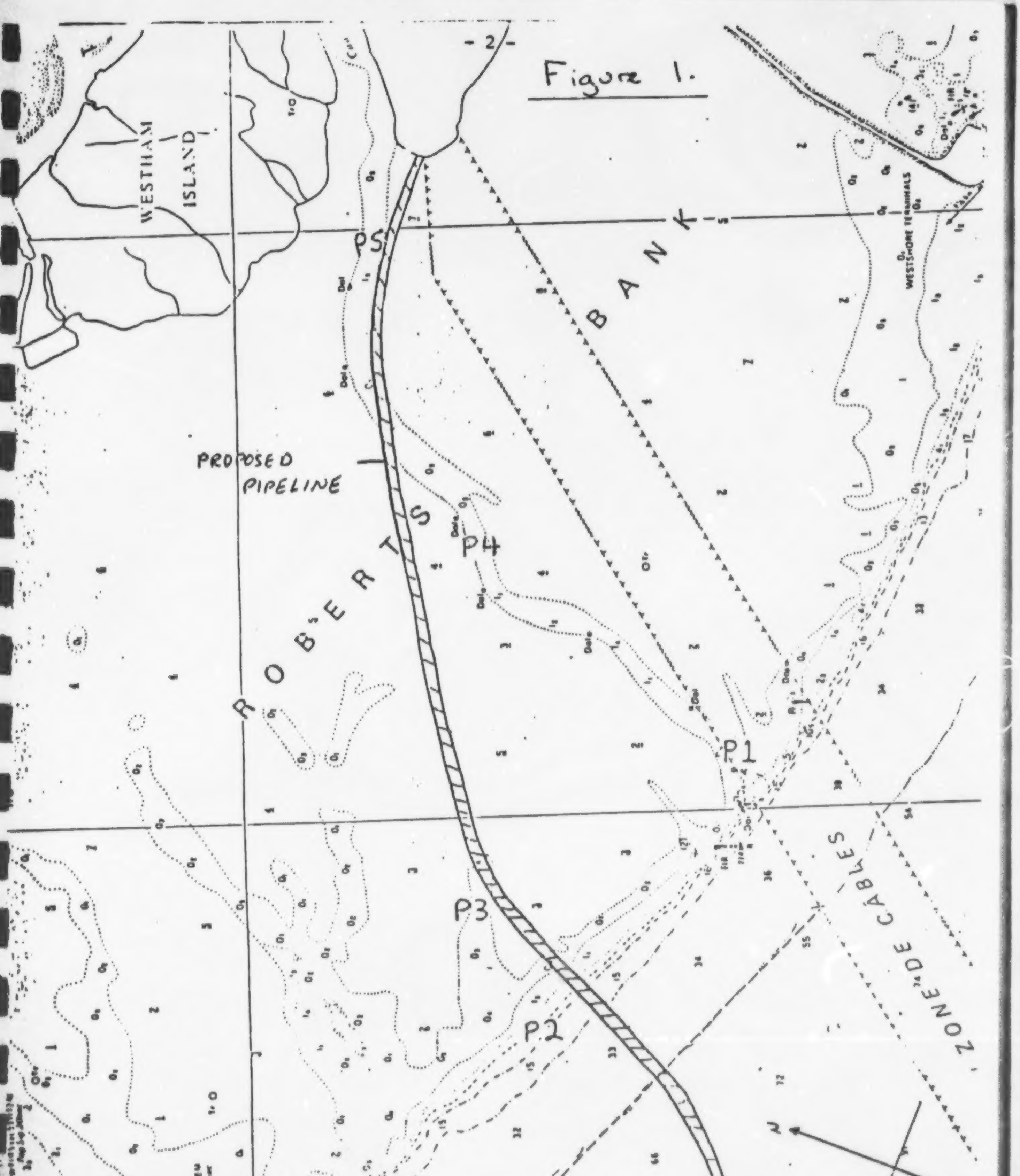


Figure 1.

WESTHAM ISLAND
PROPOSED PIPELINE
ROBERTS
BANK
P5
P4
P3
P2
P1
WESTSHORE TERMINALS
ZONE DE CÂBLES
N

MATERIALS AND METHODS

FISH

Purse Seining

Purse seining was conducted at five sites in the vicinity of Canoe Pass at Roberts Bank (Figure 1) from July 22 to August 27, 1982. At the start of the study three sites were chosen (P1, P2, P3) while in August it was decided to include 2 additional sites (P4 and P5). Sites P1 and P2 were sampled five times during the study, site P3 was sampled three times, and sites P4 and P5 were sampled twice.

The net used was a 15.2 x 3.7 m hand purse seine with 9.5 mm mesh in the wings and 6.4 mm mesh in the bunt. The net was deployed from a 19 foot Boston whaler. Sets were made as close as possible to slack tide. In all but the first sampling period a minimum of three sets were made at each site. Each set was made in depths of 3 - 5 metres of water.

Beach Seining

Beach seining was carried out on one occasion (August 6) at a sand bar near site P1. A 15.2 x 1.8 m beach seine with 6.4 mm mesh in the wings and 3.2 mm mesh in the bunt was pulled along the foreshore for 50 to 100 m.

Crab Survey

Sites P1, P2, P4 and P5 (see Figure 1) were sampled in the crab survey. P3 was not included due to time constraints and because of its relative proximity to P2.

In the crab surveys *C. magister* individuals were collected with standard .9 m diameter commercial crab pots with escape ports wired shut to ensure capture of both legal (>165 mm) and sublegal size crabs. Due to the mesh size of the traps these pots were size selective as crabs less than 110 mm were able to crawl out through the wire mesh. Consequently, data pertaining to captures of crabs less than 110 mm is only useful for qualitative purposes. Commercially caught squid (*Loligo opalescens*) was used for bait in the traps. Five traps were placed at each site in depths ranging from 2.7 to 6.4 m. The set time at each site was 24 hours, which covered one full tidal cycle.

The total number of crabs captured in the 24 hour set (catch per unit effort or CPUE) was recorded by date, time and pot number. Carapace width in millimeters was measured for each crab between the tips of the tenth anterolateral spines using a vernier caliper. Sex and shell hardness were recorded, with the latter determined by applying finger pressure to the carapace interior to the tenth anterolateral spine.

Hardness was graded on a scale of I to III as follows:

I - Hardshelled - carapace inflexible or, slightly flexible when moderate pressure is applied.

II - Intermediate - carapace flexes when moderate pressure is applied.

III - Softshelled - carapace very flexible when moderate pressure is applied. Confirmed by presence of flexibility in merus of the cheliped.

General condition was also noted, including observations of absent or regenerated walking legs or chelipeds, carapace damage, and/or abnormal structures.

RESULTS

FISH

Purse Seining

Catch data for herring and salmon is presented as catch per unit effort (CPUE) with an effort being one set of the net. It was not possible to represent the data as fish per m^3 due to the unknown volume of tidal water passing through the net and the variation in the size of each set.

A summary of herring catches during the study is provided in Table 1. The results show that there is considerable variation in the number of herring caught both between sites and also with time. Herring were not caught at site P1 except on one occasion (July 30) when there was a very large catch. Herring were caught at site P2 up until August 11. The data collected at site P3 and P4 indicates that herring could be present at these locations into late August. There were no herring caught at site P5.

Very few salmon were caught during the study and chinook was the only species detected (Table 2). Chinook smolts (average size = 131 mm) were caught on only 3 occasions and only at sites P1, P2 and P4.

Appendix I contains all of the raw data gathered during purse seining.

Table 1. MEAN NUMBER OF HERRING CAUGHT PER UNIT EFFORT

Date	P1	P2	Site P3	P4	P5
July 22	0	17.0	n/a	n/a	n/a
July 30	120.0	15.0	11.0	n/a	n/a
August 6	0	53.3	n/a	n/a	n/a
August 11	0	0	11.7	33.0	0
August 27	0	0	1.3	0	0

Table 2. MEAN NUMBER OF CHINOOK CAUGHT PER UNIT EFFORT

Date	P1	P2	Site P3	P4	P5
July 22	0	0	n/a	n/a	n/a
July 30	0.4	0	0	n/a	n/a
August 6	0	0.75	n/a	n/a	n/a
August 11	0	0	0	1.3	0
August 27	0	0	0	0	0

NOTE: n/a means that seining was not conducted on that particular day at the specific site

Beach Seining

Beach seine data is presented as CPUE for the same reasons described for purse seining. The beach seining data (Appendix 2) showed the presence of bottom fish and five juvenile herring in one of the sets. As the water temperature in the intertidal area was found to be very high at this time of the year (about 19.5°C) it was decided to curtail further beach seining activities as juvenile salmonids are known to avoid such high temperatures.

Crab Survey

One of the best measures of crab abundance is CPUE. It is not possible to generate a density estimate from trap catches due to the unknown area of trap influence.

Table 3 summarizes the crab capture data. The mean CPUE reveals that site P2 supports a substantial population relative to the other sites, no crabs were captured at site P5 while sites P1 and P4 supported intermediate sized populations. There is a definite trend in this data as the CPUE increases with proximity to the drop off at the outer edge of Roberts Bank. The mean sizes of crabs at each site also increase moving offshore from sites P4 to P1 to P2.

The hardness data (Appendix 3) indicates that many crabs have recently molted (i.e. those measuring 2 or 3 on the hardness scale).

Table 3.

SUMMARY OF SURVEY OF DUNGENESS CRABS

DATE	SITE	DEPTH (m)	TRAP #	CPUE	TOTAL (f)	TOTAL (m)	SIZE RANGE (mm)	MEAN SIZE (mm)	ST. DEV.	MEAN CPUE	ST. DEV
1982 19/08	P1	2.7-3.4	1	9	4	5	122-164	138	13.8		
			2	12	5	7	118-161	139	16.5		
			3	2	1	1	136-146	141	7.1		
			4	5	0	5	135-162	150	10.1		
			5	11	3	8	116-165	145	15.3		
			-	-	-	-	-	-	-	7.8	3.8
19/08	P2	2.8-3.4	1	23	6	17	115-167	149	13.6		
			2	14	2	12	141-167	156	7.5		
			3	20	4	16	129-174	152	10.9		
			4	22	5	17	131-172	150	11.1		
			-	-	-	-	-	-	-	19.8	3.5
24/08	P4	4.9-5.5	1	3	2	1	130-139	133	4.9		
			2	3	2	1	65- 76	70	5.6		
			3	2	1	1	132-135	134	2.1		
			4	5	3	2	122-150	141	11.1		
			5	5	4	1	116-149	134	13.2		
			-	-	-	-	-	-	-	3.6	1.2
24/08	P5	2.7-6.4	1	0	-	-	-	-	-		
			2	0	-	-	-	-	-		
			3	0	-	-	-	-	-		
			4	0	-	-	-	-	-		
			5	0	-	-	-	-	-		
			-	-	-	-	-	-	-	0	-

RECOMMENDATIONS

The preliminary data gathered for this study is fairly sparse as the work didn't begin until late in the summer. In order to get a more complete picture of fish (especially salmonid) utilization of the Canoe Pass area, we feel that more work should be done next summer with a start up date of no later than early June. We also think that more emphasis should be put on beach seining as juvenile salmonids will likely be caught in beach seines throughout the spring and early summer. Beach seining can be carried out at sites P1 and P4 at low tides and at P5 (Brunswick Point) at almost all tidal levels. It may also be a good idea to include another beach seine site in the area approximately midway between P4 and P3 on a sandbar which appears only on low tides.

The purse seining efforts seem to be adequate with a minimum of 3 sets taken at each of 5 sites. The one problem found in purse seining was that sites P3 and P2 were very hard to locate due to the lack of dolphins, buoys, etc. in the immediate area which may be used as suitable site markers. Although compass bearings were taken on several occasions this method was found to be relatively inaccurate. Therefore we recommend that these sites be precisely located and permanent markers be put in place for subsequent sampling.

In reference to the crab survey we feel that the surveys should be continued in the same manner but carried out 3 or 4 times rather than just once. A series of crab surveys will show whether or not the sub-populations are stationary or if they move around during the study period.

Appendix I
PURSE SEINING CATCHES

SITE	TIME	SET	DEPTH (m)	SURFACE TEMP-°C	CATCH
July 22, 1982					
P1	1450(+)	1		16.0	4 sandlance, 2 crangonid shrimp
P2	1320(+)	1	4	16.0	22 juvenile herring, 3 adult herring, 2 larval herring, 2 pacific tomcod, 1 sandlance, 1 staghorn sculpin, 1 dogfish
P2	1400(+)	2	3	16.0	6 juvenile herring, 1 adult herring, 2 gunnels, 3 pacific tomcod, 2 shiner sea perch, 2 sandlance, 2 staghorn sculpins, 2 starry flounders, 1 juvenile flatfish, 6 cragon id shrimp
July 30, 1982					
P1	1520(0)	1	4	17.0	1 chinook (165mm), 9 juvenile herring, 4 surf smelts, 200 sandlance
P1	1535(0)	2	4	17.0	approx. 150 juvenile herring, 60 sandlance, 3 surfs smelts, 1 anchovy
P1	1555(0)	3	4	17.0	approx. 200 juvenile herring, approx. 500 sandlance, 8 surf smelts
P2	1350(+)	1	3	17.5	1 juvenile flatfish, 5 staghorn sculpins
P2	1405(+)	2	3	17.5	11 juvenile herring, 3 sandlance, 1 juvenile flatfish
P2	1415(+)	3	3	17.5	34 juvenile herring
P3	1435(+)	1	4	18.0	33 juvenile herring, 7 sandlance, 1 cragonid shrimp
P3	1445(+)	2	3	18.0	2 sandlance, 1 cragnoid shrimp
P3	1450(+)	3	4	18.0	0

Appendix I
Purse Seining Catches cont'd

SITE	TIME	SET	DEPTH (m)	SURFACE TEMP-°C	CATCH
August 6, 1982					
P1	1215(-)	1	3	17.5	1 juvenile pacific tomcod, 1 sandlance, 1 cragonid
P1	1230(-)	2	3	17.5	0
P1	1245(-)	3	3	17.5	0
P1	1300(-)	4	3	17.5	2 staghorn sculpins, 1 sandlance, 1 starry flounder
P1	1315(-)	5	3	17.5	4 staghorn sculpins, 2 cragonid shrimp
P2	1020(-)	1	5	17.0	0
P2	1035(-)	2	4	17.0	8 juvenile herring, 2 sandlance, 1 surf smelt
P2	1050(-)	3	3	17.0	approx. 200 juvenile herring, approx. 100 sandlance, 8 surf smelts, 2 chinook (178, 154 mm)
P2	1110(-)	4	3	17.0	5 juvenile herring, 1 shiner sea perch, 1 chinook (121 mm)
August 11, 1982					
P1	1410(-)	1	4	18.0	2 crangonid shrimp
P1	1420(-)	2	4	18.0	0
P1	1425(-)	3	4	18.0	0
P2	1435(-)	1	4	18.0	0
P2	1445(-)	2	4	18.0	2 surf smelt
P2	1450(-)	3	5	18.0	0

Appendix I
Purse Seining Catches cont'd

SITE	TIME	SET	DEPTH (m)	SURFACE TEMP-°C	CATCH
August 11, 1982					
P3	1510(-)	1	4	17.5	4 juvenile herring, 7 sandlance, 1 starry flounder, 1 flatfish, 1 pacific tomcod, 1 staghorn sculpin, 5 cragonid shrimp, 1 pandalid shrimp
P3	1525(-)	2	4	17.5	28 juvenile herring, 1 surf smelt, 1 stahorn sculpin
P3	1535(-)	3	4	17.5	3 juvenile herring, 2 starry flounders, 1 pacific tomcod, 1 juvenile flatfish, 1 staghorn sculpin
P4	1330(-)	1	4	18.0	4 chinook (99,99,103,132mm), approx. 70 juvenile herring, 1 starry flounder, 25 cragonid shrimp
P4	1345(-)	2	4	18.0	12 juvenile herring
P4	1355(-)	3	4	18.0	17 juvenile herring, 1 pacific tomcod, 1 flatfish, 1 staghorn sculpin, 30 cragonid shrimp
P5	1230(-)	1	5	18.0	3 cragonid shrimp
P5	1245(-)	2	5	18.0	2 unidentified fish, approx. 80 crangonid shrimp
P5	1300(-)	3	4	18.0	100 cragonid shrimp
August 27, 1982					
P1	1240(+)	1	4	17.0	4 sandlance
P1	1250(+)	2	4	17.0	1 juvenile pipefish
P1	1255(+)	3	5	17.0	1 staghorn sculpin
P2	1215(+)	1	5	17.0	0

Appendix I
Purse Seining Catches cont'd

SITE	TIME	SET	DEPTH (m)	SURFACE TEMP-°C	CATCH
P2	1220(+)	2	5	17.0	0
P2	1230(+)	3	4	17.0	0
P3	1145(+)	1	3	-	5 juvenile herring, 1 starry flounder, 1 staghorn sculpin
P3	1150(+)	2	3	-	0
P3	1200(+)	3	3	-	0
P3	1205(+)	4	3	-	0
P4	1305(+)	1	5	17.0	0
P4	1310(+)	2	5	17.0	0
P4	1315(+)	3	5	17.0	2 larval fish
P5	1334(+)	1	4	17.0	0
P5	1340(+)	2	4	17.0	18 crangonid shrimp
P5	1345(+)	3	4	17.0	4 crangonid shrimp

Note - figure in brackets appearing after time indicates tidal status:

- = falling tide
0 = slack tide
+ = rising tide

APPENDIX 2
Beach Seining Data
August 6, 1982

Site P1, Set #1

Time - 1350
Area of Set - 12 x 100m
Max. Depth - 1m
Catch - 25 starry flounder
34 juvenile flat fish
11 staghorn sculpins
5 juvenile herring
approximately 40 crangonid shrimp

Tide - flooding
Temp. - 19.5°C
Substrate - sand

Site P1, Set #2

Time - 1410
Area of Set - 12 x 50m
Max. Depth - 1m
Catch - 24 starry flounder
14 juvenile flat fish
20 staghorn sculpins
8 crangonid shrimp

Tide - flooding
Temp. - 19.5°C
Substrate - sand

Appendix 3
CRAB DATA
August 19, 1982

SITE	TRAP	SIZE	SEX	HARDNESS	COMMENT
P1	1	128	M	1	
		148	M	1	
		140	M	2	
		143	F	2	
		164	M	1	W/O L1
		129	F	2	
		123	F	1	
		122	F	2	
		146	M	2	
	2	161	M	2	
		155	M	1	W/O R1, L3
		141	M	2	
		144	F	2	
		151	M	2	
		112	F	2	
		118	F	2	
		118	M	2	
		142	F	1	
		149	M	1	REGEN. R1
		152	M	2	
		125	F	1	
	3	136	F	1	W/O L2
		146	M	1	REGEN. L1
	4	162	M	1	W/O L3
		148	M	1	
		150	M	1	
		135	M	1	W/O L1
		156	M	1	REGEN. R1
	5	162	M	2	
		165	M	1	REGEN. L1
		142	F	2	W/O R1, 2
		134	F	1	
		161	M	2	W/O R5
		153	M	2	
		116	F	2	W/O R3, 4
		148	M	1	W/O R2
		128	M	2	
		147	M	1	REGEN. L1
		138	M	1	

Appendix 3
CRAB DATA
August 19, 1982

SITE	TRAP	SIZE	SEX	HARDNESS	COMMENT
P2	1	140	F	2	
		148	M	1	W/O R1, L5
		160	M	1	
		146	M	2	
		152	M	1	W/O R5
		160	M	1	W/O L1, 5, R1
		166	M	1	
		156	M	2	
		135	F	2	
		147	F	2	REGEN. L1
		122	F	2	
		141	M	2	W/C L1
		136	M	2	
		148	M	2	
		162	M	1	REGEN. R1
		158	M	2	
		163	M	2	W/O R5
		167	M	3	W/O R5
		142	F	1	
		150	M	3	W/O R2
		162	M	2	
		115	F	1	
		141	M	1	
	2	157	M	1	
		156	M	1	
		165	M	3	
		160	M	2	W/O R1
		165	M	1	
		149	F	1	
		150	F	1	W/O R5
		148	M	1	W/O L2, R5
		157	M	1	
		162	M	1	
		151	M	2	
		141	M	1	
		158	M	1	
		167	M	1	
	3	144	M	1	
		156	M	1	
		158	M	2	
		162	M	2	
		150	M	1	
		150	M	1	
		150	F	1	

Appendix 3
CRAB DATA
August 19, 1982

SITE	TRAP	SIZE	SEX	HARDNESS	COMMENT
P2 cont	4	160	M	2	W/O L1, 2, 3
		159	M	1	
		146	F	1	
		150	F	1	W/O L1
		142	M	1	
		148	M	1	REGEN. L1, R1
		153	F	3	
		129	M	2	
		131	M	1	
		155	M	1	
		174	M	1	W/O L1, 2, 3 REGEN. R1
		168	M	1	
		154	M	1	W/O R5
		159	M	1	W/O L4
		152	M	1	
		158	M	2	
		172	M	2	W/O R3
		151	M	1	
		134	F	1	W/O L1
		154	M	2	
		137	F	1	
		140	F	2	
		131	F	1	
		147	M	1	
		154	M	1	
		134	M	1	W/O R3, 4, 5, L4, 5
		171	M	1	
		153	M	1	
		153	M	2	
		144	,	1	W/O L2
		142	M	1	W/O L5, R1, 3
		153	M	2	W/O R2
		160	M	2	W/O R2
		141	F	1	
		161	M	2	
		152	M	1	

Appendix 3
CRAB DATA
August 24, 1982

SITE	TRAP	SIZE	SEX	HARDNESS	COMMENT
P4	1	131	M	2	
		139	F	1	
		130	F	3	
	2	76	M	2	
		65	F	2	
		69	F	2	
	3	135	M	3	
		132	F	3	REGEN. L1
	4	147	F	2	
		142	F	1	W/O R2, 5, L4, REGEN. L1
		150	M	1	
		145	M	1	W/O R1
		122	F	3	W/O R5
	5	144	F	1	W/O L1
		134	F	1	W/O R4, REGEN. L4
		116	M	2	
		127	F	3	REGEN. L1
		149	F	1	

5 1 *
2 *
3 * NOTHING
4 *
5 *

NOTE:

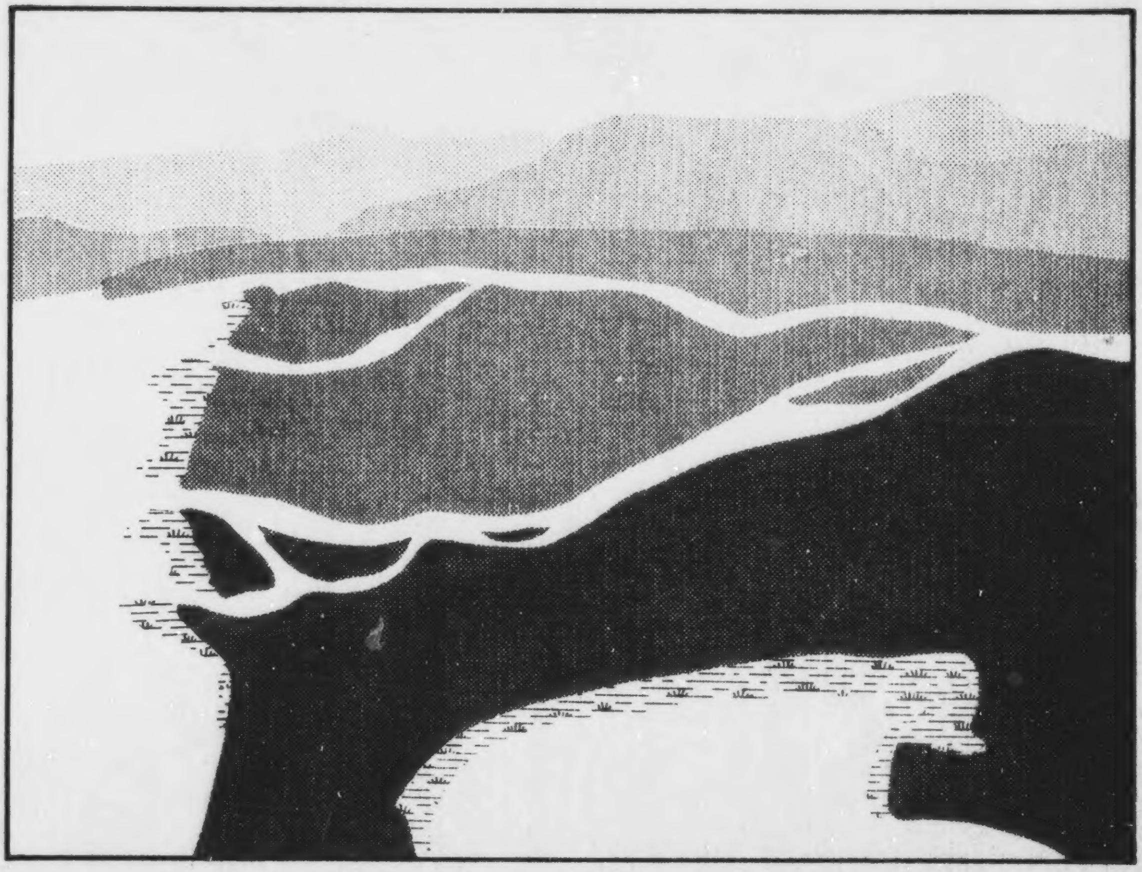
W/O - means without
R - refers to right side
L - refers to left side
1-5 - refers to the legs counting from front (ie. chelipid=1) to back
REGEN. - means the orginal leg has been lost and a new one has regenerated

Volume

2

Ex 114B

ENVIRONMENTAL IMPACT ASSESSMENT
OF
CONSTRUCTION
OF A NATURAL GAS PIPELINE
ACROSS ROBERTS BANK



Volume 2: The Impact of Pipeline Construction on the Physical Environment of Roberts Bank

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ENVIRONMENTAL IMPACT ASSESSMENT OF CONSTRUCTION OF A NATURAL GAS PIPELINE ACROSS ROBERTS BANK

Volume 2

The Impact Of Pipeline Construction On The Physical Environment Of Roberts Bank

B.C. HYDRO

FEBRUARY, 1983

MONENCO PIPELINE CONSULTANTS LIMITED

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18 April 1983

B. C. Hydro
Vancouver Island Project
555 West Hastings
Vancouver, B. C.
V6B 4T6

Attention: Mr. K. G. Farquharson,
Coordinator of Environmental Affairs

Dear Sir:

We are pleased to submit our report entitled "The Impact of Pipeline Construction on the Physical Environment of Roberts Bank".

The report covers three main topics: Firstly, the physical regime of the area is described, including the bathymetry, geology, oceanography and climatology.

Secondly, the design of the pipelines, and the proposed construction equipment and techniques are described.

Finally, the impacts of the construction and operation of the pipelines on the physical environment are described and assessed. It is concluded that these impacts would be primarily of a temporary nature, and can be minimized by careful planning and supervision of the construction.

We trust that you will find the report satisfactory, and look forward to discussing it with you in due course.

Yours very truly,

J. R. Muir

JRM/bb

INTRODUCTION

B. C. Hydro is considering extending its natural gas transmission/distribution system to and on Vancouver Island by underwater pipeline from the lower mainland. The proposed route involves a crossing of Roberts Bank. B. C. Order-in-Council 908 requires that the proponent of any development on Roberts Bank prepare an environmental impact assessment report acceptable to the Minister of Environment.

In January 1981, B. C. Hydro presented to the OIC 908 Review Committee an outline of the proposed project and in March the Committee issued the final terms of reference for the EIA Study. This volume of the study was prepared to summarize the physical environment of Roberts Bank, to describe the proposed construction methods and the impact of the prevailing climatic conditions on construction sequences and schedules, to describe all ancillary activities, and to assess the impact on the physical environment of the construction and operation of the proposed pipeline.

SUMMARY

This report summarizes the existing environmental, geological and physical conditions on Roberts Bank, describes the methods proposed for the construction and operation of the Roberts Bank section of the B. C. Hydro Vancouver Island Gas Transmission Pipeline and assesses their impact on the physical environment.

Part 1 summarizes wind data collected from two recording stations in the area, between 1962-1973 and presents exceedance charts for winds exceeding 9 m/s. A summary of the temperature and precipitation means and extremes measured between 1941 and 1970 at Steveston, B. C. is included, and the records of reduced visibility under 1 mile and 3 miles at Vancouver Airport over the last 14 years are presented.

Part 2 presents the results of wave hindcasting based on the wind data summarized in Section 1, and compares these results with actual wave measurements. The prevailing tidal currents, based on a current measurement program in 1979, are described, and flow velocities in the Canoe Pass arm of the Fraser River, based on a measurement program in 1980 are described. A detailed bathymetric map of the area, surveyed in 1980 is presented and the results of two studies of channel scour across Roberts Bank, both of which estimated a maximum scour depth of 7 m, are discussed. It is reasoned that this depth is conservative for points away from the

existing Canoe Pass channel and towards the outer edge of the Bank. Finally, the channel morphology is described, and historic aerial photographs of Roberts Bank are compared.

Part 3 describes the various geomorphological features of the area, and presents the results of a 1980 soil sampling program. These show that the material across the intertidal flats is generally a fine sand, with less than 10% silt, whilst the foreslope area is mainly silty sand, with 50% silt content. The effects of earthquake loading on the area are described, and the conclusion reached is that in an extreme earthquake event some soil liquefaction could occur, but no damage to the pipeline is anticipated.

Part 4 describes two candidate designs for the twin pipelines, 406 mm and 324 mm outside diameter. The reasons for selecting the route from Brunswick Point to the foreslope crest are described, and the burial depth of 7 m cover over the pipeline for the first 6 km of the route from Brunswick Point, and 5 m depth for the last 3 km, is presented in the form of a route profile.

Part 5 describes the proposed construction and operation activities. The construction method selected is the "bathtub" method in which the trench is excavated by a suction dredge and the material discharged some distance behind the dredge by a backfill pontoon. A laybarge floats between these two units, and welds together sections of pipe, laying both lines simultaneously into the bottom of the trench. Each item of equipment is described and the effects of the climatic and marine conditions summarized in Part 1 are evaluated. A 120 m wide working area through the tidal marshes, and 200 m wide area across the remainder of Roberts Bank are proposed. The sequence of operations are presented both descriptively and pictorially, for two alternate construction directions, one seawards from Brunswick Point and the other landwards from the foreslope.

In addition, the methods are described for constructing the shore approach trench and for crossing the dyke at Brunswick Point.

Finally the assumptions for the preparation of the construction schedules, the impact of weather downtime and schedule constraints are discussed. Assuming a June 15th start date, the estimated duration for the landwards construction sequence is 199 days, including 15 days of weather downtime. Assuming a July 1st start date for the seawards construction sequence, the estimated duration is 214 days including 33 days of weather downtime.

The difference in durations for the two sequences is reflected in the cost estimates, which are $18.3 million for the landwards sequence and $19.1 million for the seawards sequence. An economic and technical comparison is made of the two sequences, and the conclusion is drawn that the landwards sequence is preferred.

Part 6 describes the proposed annual inspection. It is argued that the only maintenance that would be required is the backfilling of deep scour holes which may occur in the Canoe Pass section of the line. It is considered that the possibility of a repair being required is very slight, but an outline of the work that would be involved in effecting one is included.

Part 7 describes the impact of construction on the physical environments of the various areas of the bank. The losses of backfill material are estimated to be between 5 - 8% of the total volume dredged, or approximately 220,000 m^3, and an estimate is made of the size and concentration of the plume resulting from these losses. The overall conclusion of this section is that there would be a large impact on the physical environment during construction, but that the long term effects would be small.

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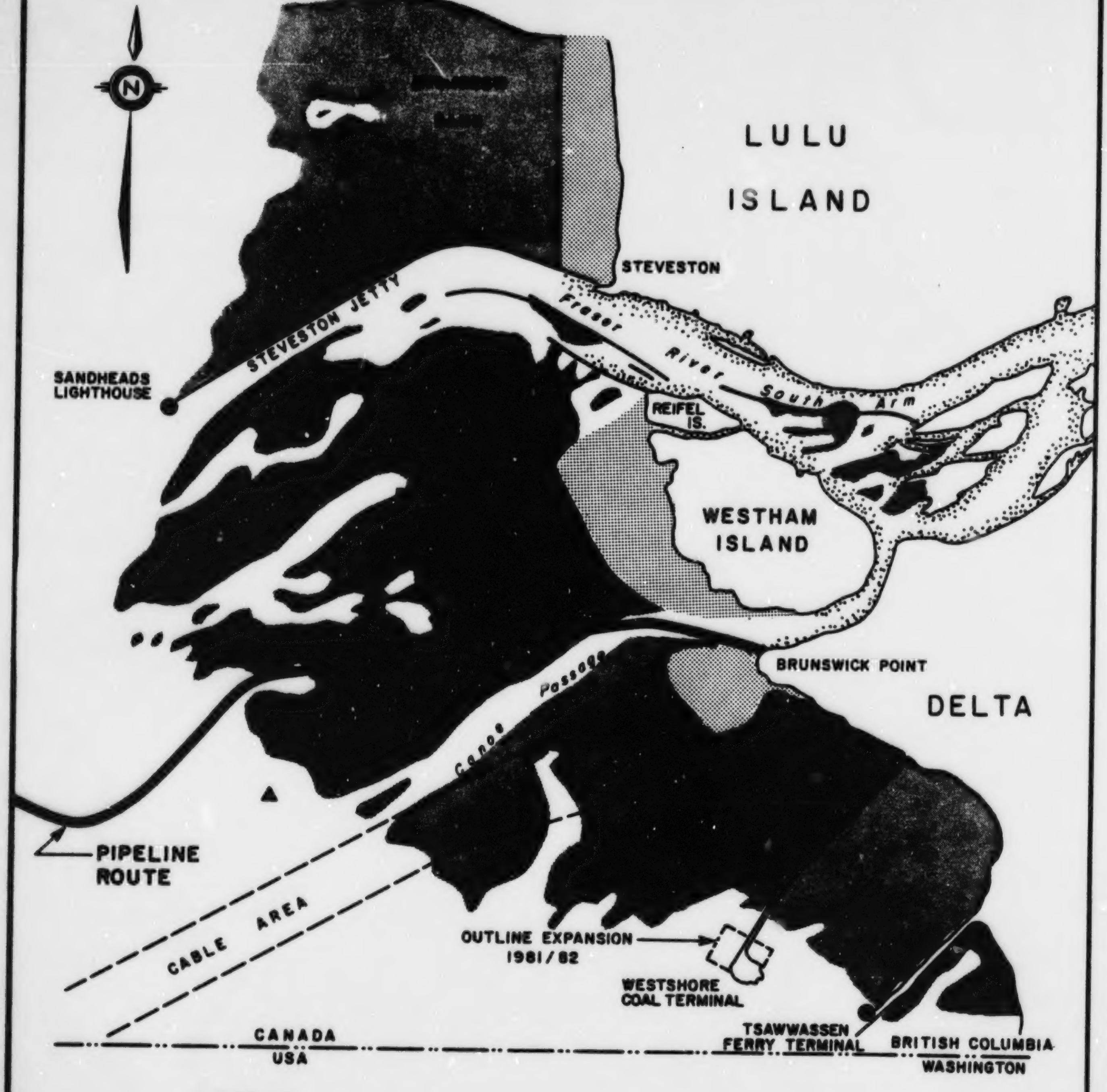
N
LULU ISLAND
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REIFEL IS.
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WASHINGTON

LEGEND

▨ TIDAL MARSH

■ INTERTIDAL FLATS

● ATMOSPHERE ENVIRONMENT SERVICE DATA COLLECTION STATION

▲ WAVE MEASUREMENT LOCATION STATION 108

PLATE S-1

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

ROBERTS BANK KEY PLAN

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PART 4 PIPELINES DESCRIPTION, ROUTE AND PROFILE

PART 5 CONSTRUCTION METHODOLOGY

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PART 1 - CLIMATIC CONDITIONS

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1.5 Percentage Time Winds Exceeded 9 m/s (20 mph) Sandheads Lighthouse Records (May 1967 - November 1979)

PLATES

PLATE

1.1 Percentage Frequency Visibility under 1 Mile and 3 Miles, Vancouver Airport.

INTRODUCTION

Climatic data is collected by the Pacific Region, Atmospheric Environment Service, and the locations of their stations are shown on Summary Plate S-1.

1.1 TEMPERATURE AND PRECIPITATION

A summary of the temperature and precipitation means and extremes recorded at Steveston, B. C. over 29 years (1941-1970) by the Atmospheric Environmental Service are contained in Table 1-1. The extreme temperatures range from an extreme high of 34°C in August to an extreme low of -21°C in February.

1.2 WIND

Wind data for Roberts Eank has been collected over 11 years (1962-73) at Tsawwassen Ferry and 9 years (1967-76) at Sand Heads Lighthouse. The data is summarized in Tables 1-2 (Tsawwassen) and Tables 1-3 (Sand Heads).

A feature of the Roberts Bank area are the easterly and southeasterly winds which prevail for much of the year. During December and January, up to 50% of the time, strong easterly winds predominant, due to cold air moving seaward from the Fraser Valley. In the warmer months, April through September, a secondary maximum occurs and winds prevail from the west quadrant 10-25% of the time. This tends to be an onshore wind during the daytime. At Sand Heads during April through October the winds do not have any single prevelant direction, as they blow equally frequently (around 20% of the time) from the east, southeast and northwest. At Tsawwassen however, the dominant winds during April through to October are from the southeast.

The average annual wind speed at Sand Heads is 5.3 m/s, which is slightly higher than the value of 4.9 m/s at Tsawwassen. The average monthly windspeed at Sand Heads ranges from 6.5 m/s in December to 4.5 m/s in August and at Tsawwassen from 6.3 m/s in December to 3.8 m/s in September. At both stations the lowest winds occur between May and September and the highest winds occur in December and January.

The frequency of strong winds greater than 9 m/s (20 mph) at Tsawwassen Ferry and Sand Heads Lighthouse has been tabulated in Tables 1-4 and 1-5 respectively. The tables show the percentage time the wind exceeded 9 m/s (20 mph) during each month of the year for each compass point. During the months of December and January the wind exceeded 9 m/s for more than 20% of the time, for 15% of the time from the southeast quadrant and 4-5% of the time from the northwest. In the summer months the wind exceeded 9 m/s for 5% of the time at Tsawwassen and 10% of the time at Sand Heads, but more than half of the time the wind was from the northwest. During spring and autumn strong winds occurred approximately 11-15% of the time; they were predominantly from the east or southeast at Tsawwassen and from the east, southeast, and northwest at Sand Heads.

1.3 VISIBILITY

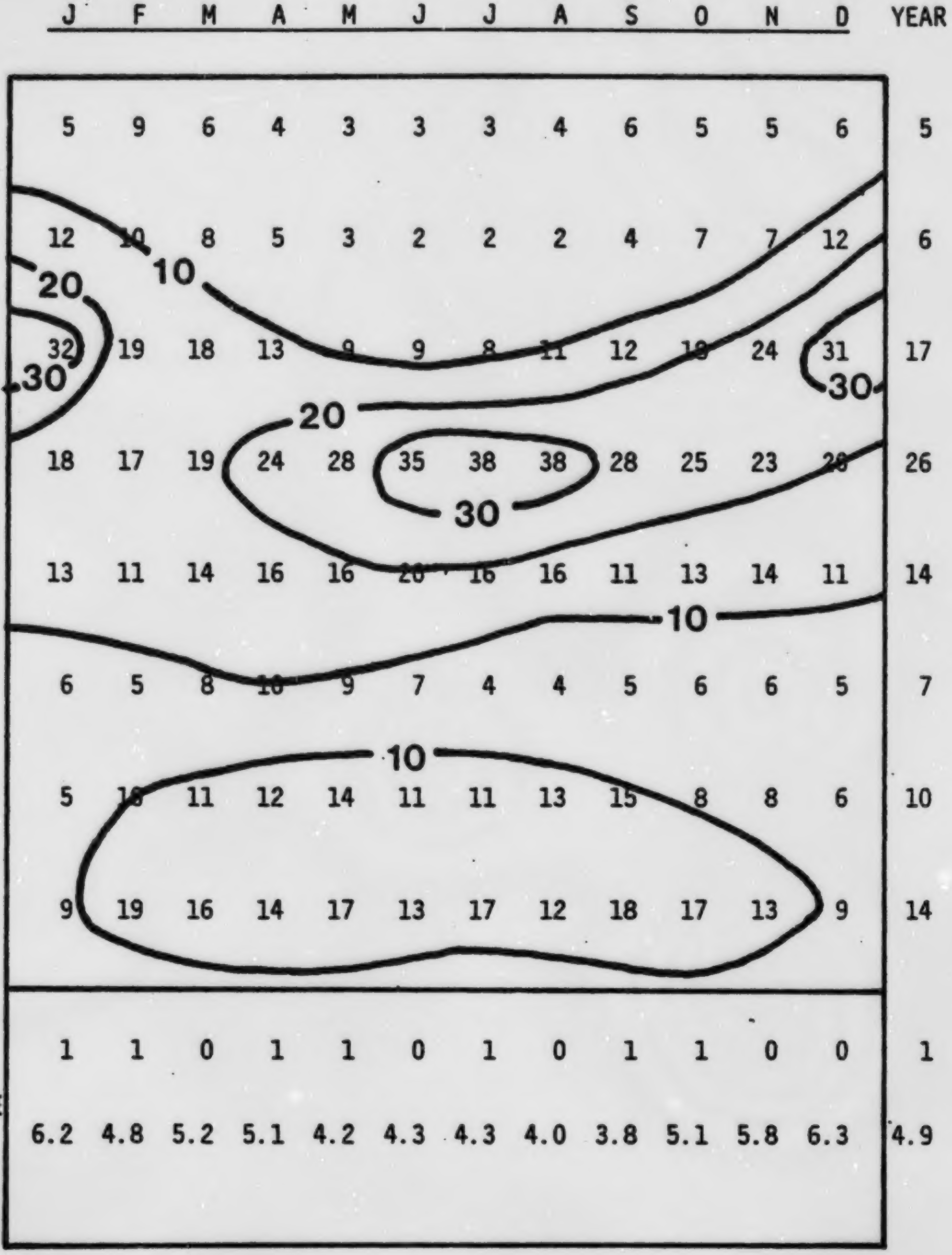
Statistics on visibility were obtained for 14 years of records at Vancouver Airport. Plate 1-1 presents the percentage frequency occurrence of visibility under one mile (1.6 kilometres) and 3 miles (4.8 kilometres).

Visibility under three miles during the warmer months March through August occurs not more than 6% of the time. During the colder months September through February visibility under three miles occurs 18 to 26% of the time before 1200 hours, which reduces to 9 to 17% of the time between 1200 and 2400 hours. The visibility during the fall and winter is less than one mile for approximately 10% of the time between 0000 and 1200 hours.

TABLE 1-1
TEMPERATURE AND PRECIPITATION SUMMARY FOR STEVESTON, B. C. 1941-1970

Item	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)													
Daily Mean Temperature	2.2	4.1	5.6	8.6	11.9	14.7	16.7	16.3	13.7	9.6	5.7	3.5	9.4
Mean Daily Maximum Temperature	5.6	8.1	10.0	13.4	17.3	20.1	22.7	22.3	19.4	14.3	9.5	6.7	14.1
Mean Daily Minimum Temperature	-1.0	0.2	1.2	3.8	6.6	9.4	10.8	10.4	7.9	4.8	1.9	0.3	4.7
Extreme Maximum Temperature	14.4	16.7	19.4	25.0	28.9	30.0	31.7	34.4	29.4	26.1	18.9	15.0	34.4
Extreme Minimum Temperature	-19.4	-21.1	-12.2	-4.4	-3.3	1.7	3.3	1.7	-3.9	-7.2	-15.0	-19.4	-21.1
Number of Days with Frost	16	14	12	4	1	0	0	0	1	3	10	14	73
Precipitation (mm)													
Mean Rainfall	121	100	77	56	50	42	26	37	57	117	135	139	954
Mean Snowfall	168	56	41	3	0	0	0	0	0	0	15	117	406
Mean Total Precipitation	138	106	82	56	50	42	26	37	57	117	137	152	994
Greatest Rainfall in 24 Hours	61	44	49	35	37	36	47	38	58	57	73	56	73
Greatest Snowfall in 24 Hours	406	381	343	102	0	0	0	0	0	0	203	229	406
Greatest Preciptation in 24 Hours	61	44	49	35	37	36	47	38	58	57	73	57	73
Number of Days with Measurable Rain	17	14	15	13	10	9	6	7	9	15	18	19	152
Number of Days with Measurable Snow	4	2	1	1	0	0	0	0	0	0	1	2	10
Number of Days with Measurable Precip.	19	14	15	13	10	9	6	7	9	15	18	20	155

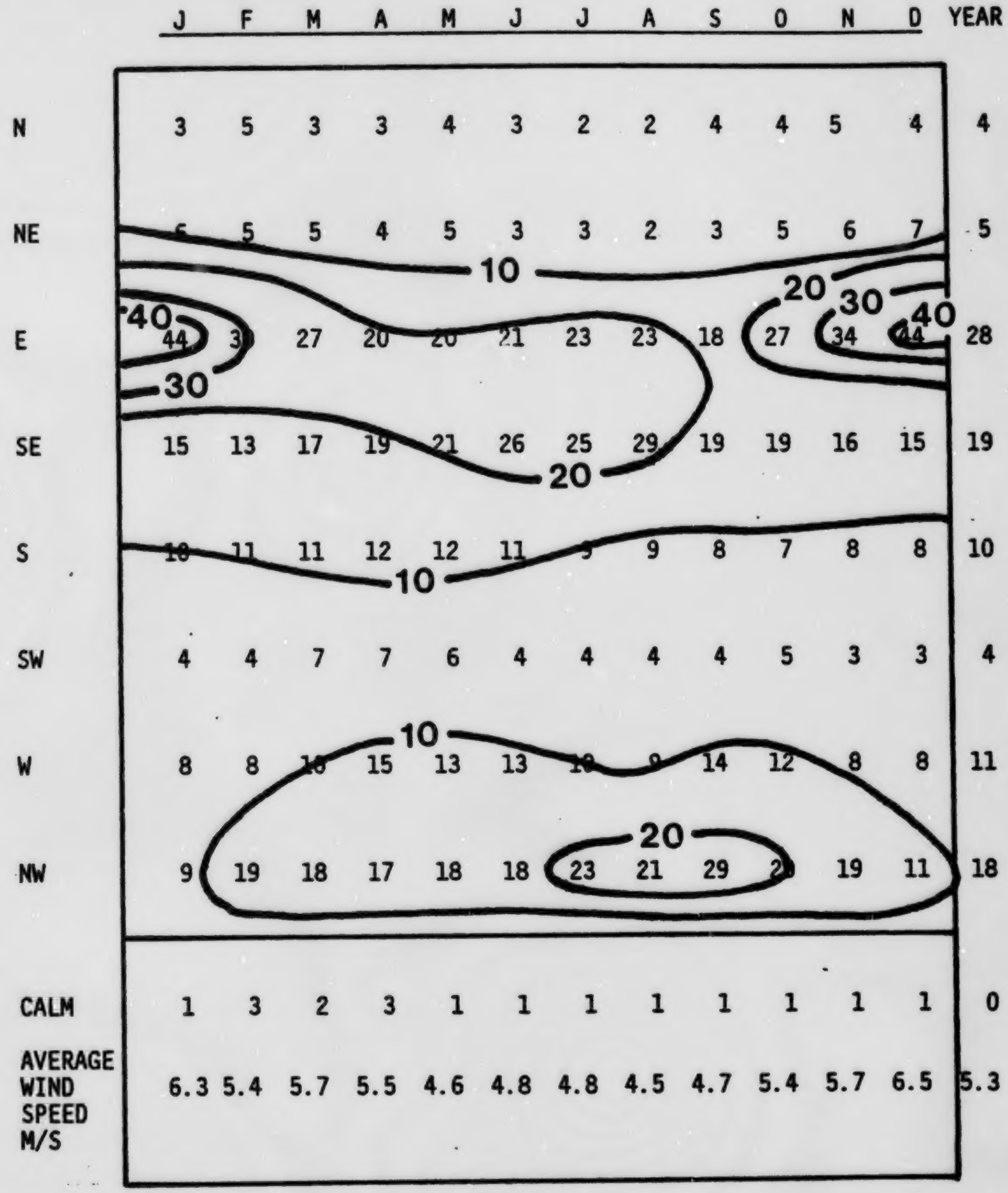
TABLE 1-2



	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
N	5	9	6	4	3	3	3	4	6	5	5	6	5
NE	12	10	8	5	3	2	2	2	4	7	7	12	6
E	32	19	18	13	9	9	8	11	12	18	24	31	17
SE	18	17	19	24	28	35	38	38	28	25	23	20	26
S	13	11	14	16	16	20	16	16	11	13	14	11	14
SW	6	5	8	10	9	7	4	4	5	6	6	5	7
W	5	10	11	12	14	11	11	13	15	8	8	6	10
NW	9	19	16	14	17	13	17	12	18	17	13	9	14
CALM	1	1	0	1	1	0	1	0	1	1	0	0	1
AVERAGE WIND SPEED M/S	6.2	4.8	5.2	5.1	4.2	4.3	4.3	4.0	3.8	5.1	5.8	6.3	4.9

Percentage Frequency Wind Direction (and Calms) and Mean Wind Speed by Months Tsawwassen Ferry Terminal, B. C. (Jan 1962 - Feb. 1973)

TABLE 1-3



	J	F	M	A	M	J	J	A	S	O	N	D	YEAR
N	3	5	3	3	4	3	2	2	4	4	5	4	4
NE	6	5	5	4	5	3	3	2	3	5	6	7	5
E	44	30	27	20	20	21	23	23	18	27	34	44	28
SE	15	13	17	19	21	26	25	29	19	19	16	15	19
S	10	11	11	12	12	11	9	9	8	7	8	8	10
SW	4	4	7	7	6	4	4	4	4	5	3	3	4
W	8	8	10	15	13	13	10	9	14	12	8	8	11
NW	9	19	18	17	18	18	23	21	29	20	19	11	18
CALM	1	3	2	3	1	1	1	1	1	1	1	1	0
AVERAGE WIND SPEED M/S	6.3	5.4	5.7	5.5	4.6	4.8	4.8	4.5	4.7	5.4	5.7	6.5	5.3

Percentage Frequency Wind Direction (and Calms) and Mean Wind Speed by Months. Sandheads Lightstation, B. C. (May 1967 - December 1976)

GR75H

TABLE 1-4

Percentage Time Winds Exceeded 9 m/s (20 mph)

Tsawwassen Ferry

(Records May 1961 - November 1975)

	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	TOTAL
JANUARY	0.2	1.3	4.8	6.7	5.9	1.5	1.4	2.9	24.7
FEBRUARY	-	0.8	1.0	3.9	2.5	0.5	1.2	2.6	12.5
MARCH	-	0.3	2.3	5.8	3.1	0.6	0.9	2.8	13.0
APRIL	-	0.1	1.1	3.3	1.6	0.6	1.8	3.6	12.1
MAY	-	-	0.6	1.7	1.0	0.2	0.6	2.5	6.6
JUNE	-	-	0.3	1.4	0.4	0.1	0.6	3.4	6.2
JULY	-	-	0.2	1.2	0.6	-	0.4	2.9	5.3
AUGUST	-	-	0.1	1.2	0.2	0.1	0.5	1.3	3.3
SEPTEMBER	-	-	0.2	1.2	0.2	0.2	1.1	1.6	4.5
OCTOBER	0.2	0.3	1.5	5.0	2.2	0.4	1.4	2.5	13.5
NOVEMBER	-	0.2	3.2	7.4	3.5	0.4	0.7	2.3	17.7
DECEMBER	-	1.7	4.8	9.5	5.7	0.7	1.5	1.9	25.8
AVERAGE	-	0.4	1.68	4.0	2.2	0.4	1.0	1.5	12.2

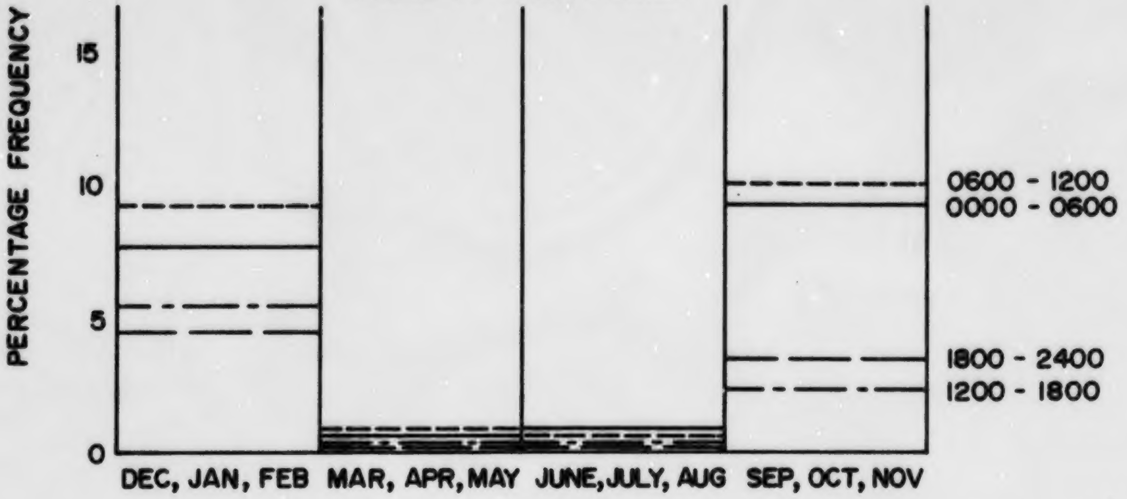
TABLE 1-5

Percentage Time Winds
Exceeded 9 m/s (20 mph)
Sand Heads Lighthouse
(Records May 1967 - November 1979)

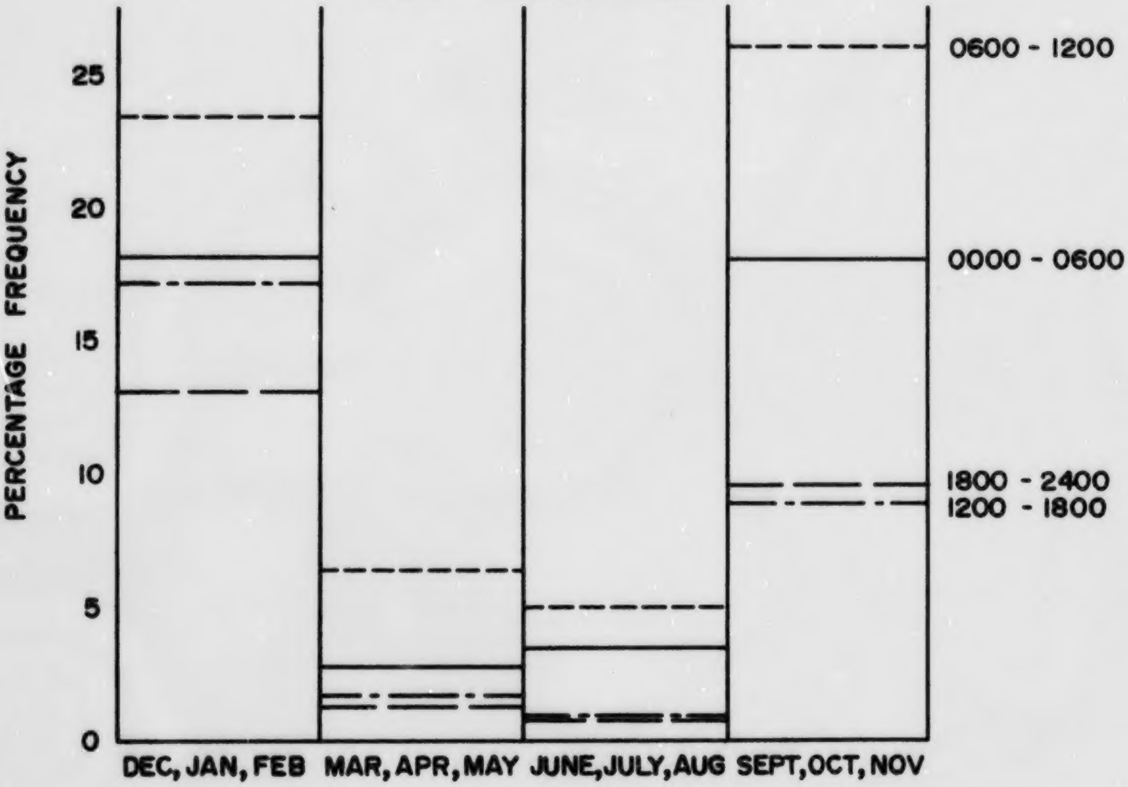
	N.	N.E.	E.	S.E.	S.	S.W.	W.	N.W.	TOTAL
JANUARY	0.1	0.2	4.4	4.8	3.1	0.7	2.4	3.0	18.7
FEBRUARY	2.0	-	3.8	5.3	3.2	0.8	1.6	2.2	17.1
MARCH	-	0.2	2.9	4.8	2.8	0.6	2.5	5.6	19.4
APRIL	-	-	1.6	3.8	1.6	0.8	3.9	4.5	16.2
MAY	-	-	0.7	2.3	0.5	0.7	2.0	3.9	10.1
JUNE	0.1	-	0.8	1.5	0.4	0.2	2.2	5.1	10.3
JULY	0.4	-	0.7	1.6	0.2	-	1.0	6.2	10.1
AUGUST	0.1	-	1.1	1.7	0.4	0.1	-.7	3.8	7.9
SEPTEMBER	0.1	-	1.0	1.7	1.1	-	2.1	4.3	10.3
OCTOBER	0.1	0.1	3.3	5.1	1.6	0.3	2.9	3.4	16.8
NOVEMBER	-	0.2	4.8	5.5	2.4	0.5	2.1	2.7	18.2
DECEMBER	0.2	0.3	6.5	7.6	3.9	0.8	3.0	4.1	26.4
AVERAGE	0.1	0.1	2.6	3.8	1.8	0.5	2.2	4.1	15.1

mpc **MONENCO PIPELINE CONSULTANTS LTD.**

VISIBILITY UNDER 1 MILE



VISIBILITY UNDER 3 MILES



14 YEARS OF RECORDS
AT VANCOUVER AIRPORT

PLATE 1-1

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

PERCENTAGE FREQUENCY
VISIBILITY UNDER 1 MILE AND
3 MILES, VANCOUVER AIRPORT

PART 2

MARINE CONDITIONS

PART 2 - MARINE CONDITIONS

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2.1 WAVES

INTRODUCTION

The Strait of Georgia is an enclosed body of water about 160 kilometres long and about 30 kilometres wide at its mid-point. The strait is protected from the waves and swell of the Pacific Ocean by Vancouver Island to the west and the Gulf Islands to the south. As a result, wave generation in the Strait of Georgia is limited by wind fetch (the uninterrupted stretch of water over which the wind blows) and wind speed. The highest waves at any location will occur in the directions of the largest fetches, which for a point offshore of Roberts Bank are from the northwest (64 km) and the southeast (40 km).

211 WAVE CLIMATE RECORDS

Between 7 February 1974 and 3 April 1976 the Marine Environmental Data Service (MED's) carried out a wave measurement programme on the edge of Roberts Bank, south of the Canoe Pass exit, in approximately 138 m water depth, as shown in Plate S-1. 3,880 wave height observations were made at three hour intervals during this period, in which 1219 calm periods were recorded. The majority of the remaining waves had heights less than 0.5 m and periods less than four seconds.

Plate 2-1 presents a scatter diagram of significant wave height (the average of the highest one-third of the waves) versus period for these records. The mean significant wave height is 0.42 m and the mean period is 3.6 seconds. On 24 May 1978 the highest significant wave height of 2.16 m was recorded with a period between 5 and 6 seconds.

The period histogram computed from Plate 2-1 is presented in Plate 2-2 and shows the percentage of wave records for each period range. The histogram indicates the recorded waves had periods of less than 5 seconds 90% of the time, and the most frequently occuring periods were between 3 and 4 seconds. The significant wave height versus exceedance is plotted on Plate 2-3. The plate shows the significant wave exceeded 0.9 m 6% of the time.

No direct measurements of wave direction were made, and Beak Consultants(1) estimated wave directions for waves greater than 1 m high by interpolating from hourly wind observations at Sand Heads and Tsawwassen Ferry Terminal for 137 cases. The results are presented in Plate 2-4. The direction in which the waves travel is northwest to west in 79 cases (58% of the time) and southeast in 32 cases (23% of the time). These are the two directions which have the longest reach, and therefore winds from these directions would generate the highest waves offshore of Roberts Bank.

The monthly variation in wave height is presented in Table 2-1. For each month of record the monthly mean and maximum monthly significant wave height are presented. The heights range from 0.3 - 0.5 m and 1.1 - 2.2 m respectively. There were no major differences observed between the seasons, which may in part be due to the lack of records from the winter of 1974/75.

212 WAVE CLIMATE HINDCASTING

Ten years of recorded wind date from Sand Heads Lighthouse for the period May 1967 to April 1977 were used by Western Canada Hydraulics Ltd.(2) to hindcast the wave climate for offshore Roberts Bank.

87,439 wave heights and periods were computed from hourly records, of which 22,319 had wave heights less than 0.3 metres and periods 0-1 seconds. These were classed as calm periods. The results are presented in Plate 2-5 as a scatter diagram of significant wave height versus period. The highest significant wave obtained in the 10 years of hindcasting was between 3.00 and 3.30 m with a period of between 8 and 9 seconds. The highest hindcast waves for each compass direction and their return period are tabulated in Table 2-2. The highest waves were from the southeast and northwest directions. The significant wave height versus exceedance is plotted on Plate 2-6 and indicates that during the period of hindcasting the significant wave exceeded 0.9 m approximately 3% of the time.

213 WAVE CLIMATE ON THE INTERTIDAL FLATS

In general, the wave climate on the tidal flats would be less severe than the offshore wave climate as recorded and predicted in Sections 211 and 212. Bottom friction would reduce the height of waves as they travel across the banks. At low tide, when the flats are exposed, the waves would break on the upper reaches of the foreslope.

A model was prepared by Western Canada Hydraulics Ltd.(2) to consider the effects of wave refraction, shoaling and friction attenuation as the waves move across the banks. An example of the wave attenuation results obtained is shown in Plate 2-7 with the waves approaching from the southwest. The amount of wave attenuation can be judged by comparing the increase in width between the approaching rays and the rays on the banks. The analysis showed, where the depth of water was sufficient, waves equal in height to those offshore could be expected on the outer half of the banks. The maximum wave at a given location in the intertidal zone is limited by water depth. The depth of water over the bank is between 2 and 3 m at high tide and the wave heights are limited to between 0.65 and 0.8 times the water depth depending on the bottom slope. Therefore at high tides, waves up to 1-2 m high can be expected to occur across the banks.

214 EXTREME WAVE HEIGHTS

The Weibull distribution has been found to give a good statistical description of wave heights and can be used to extrapolate extreme wave heights. The distribution assumes that meteorological and topographic conditions allow waves of greater heights to be generated. The Strait of Georgia has a low width/length ratio, which suggests the wave generation would be significantly lower than that expected over more open water. The exceedance diagrams based on a Weibull distribution for the recorded and hindcast significant waves are shown in Plates 2-8 and 2-9 respectively.

The exceedance diagram for the recorded waves (Plate 2-8) when extrapolated indicates a one year return period significant wave of 2.5 m and a ten year return period significant wave of 3.6 m. A one year return period wave is that wave which on average occurs once per year. Similarly the ten year return period wave is that wave which on average occurs once every ten years. The exceedance diagram for the hindcast waves (Plate 2-9) when extrapolated indicates a one year significant wave of 3.0 m and ten year significant wave of 4.5 m.

Plate 2-4 indicates that high waves occur most frequently from the northwest quadrant and the southeast quadrant. These are the directions of the greatest fetches, and the highest waves would be generated offshore of Roberts Bank and over the intertidal flats when the wind blows from either direction. (See Section 1.2.)

2.2 TIDES

Two tide measuring stations exist close to the area of Roberts Bank at Sand Heads and Tsawwassen and for both stations tidal levels are predicted by the Hydrographic Service. The tides at both these points can be taken as representative of those on the bank, but variations in tide heights and times can be expected in the areas of fresh water inflow around Canoe Pass and the Fraser River.

Plate 2-10 presents tide data recorded by Environment Canada at Tsawwassen in 1977. The graph plots water level against frequency of occurrence.

The tide is mainly semi-diurnal, meaning that there are two complete oscillations per day, but one is usually considerably stronger than the other. Although there are two high and two low water levels approximately every 25 hours, there is a difference in elevation between successive high waters (and successive low waters) called the climate inequality. This inequality is more pronounced for successive low waters.

There is also a general lunar cycle with the largest tidal swings (about 4.0 m) occurring during the new moon and full moon and known as spring tides. The lowest tidal swings, or neap tides (about 2.5 m swing), occur during the first and last quarter. During the winter and summer months the maximum tides occur with swings of 4.5 m on spring tides.

2.3 CURRENTS

231 TIDAL CURRENTS

Although the transport of water in and out of the Strait of Georgia by the tides takes place at both north and south ends, the exchange through the southern channels is about 15 times that through the northern ones. Throughout the central Strait of Georgia, the flood currents (rising tide) move northwest more or less parallel to the axis of the Strait. Ebb currents (falling tide) flow essentially southeast and tend to be weaker and of shorter duration. Offshore of Roberts Bank the maximum speeds are in the range 0.85 - 1.1 m/s at a depth of 15 m(1), and the surface layer (top 15 m) is often influenced by the wind. For example a strong northwesterly wind of 10 - 13 m/s would drive the surface layer to the southeast at speeds of up to 1.5 m/s dominating the weak tidal currents during this period.

Velocities of the tidal currents over Roberts Bank are presented in Plates 2-11 and 2-12, and are based on field work carried out by Western Canada Hydraulics Laboratories(2). On the flood tide the flow is landwards, and recorded speeds varied from 1 m/s at the edge of the foreslope to 0.13 m/s closer inshore. Bottom speeds are similar to surface speeds. During late flood a large clockwise circulation pattern develops between the South Arm of the Fraser and the Westshore Coal Terminal. This causes a southerly flow across Canoe Pass and surface velocities of 0.4 m/s have been recorded.

This circulation quickly breaks up as the ebb tide, and seaward flow begins in Canoe Pass Channel. Across the intertidal flats speeds of 0.30 m/s at the surface and 0.16 m/s at the bottom have been recorded during an ebb tide. In the vicinity of Canoe Pass Channel the speeds are higher, and surface speeds of 0.45 m/s have been recorded.

The velocities recorded in Plates 2-11 and 2-12 are representative of those to be found over the intertidal flats during an average tidal cycle. However, higher velocities would occur during a strong spring tide.

232 CHANNEL CURRENTS

When the tide is ebbing, the flow through Canoe Pass is strongest because it is augmented by the release of tidal storage in the Fraser Delta. During a flood tide the flow is weakest, and except during extreme Fraser River discharges, the flow direction reverses itself and salt water enters Canoe Pass at Brunswick Point. Peak flows in the Fraser River system are associated with the Spring snowmelt and runoff, and generally occur in the months of May through July. Field measurements of channel velocity during the 1980 freshet (May-July) have been made by Northwest Hydraulics(3) at the positions of the six navigational dolphins along Canoe Pass. (Plate 2-14). The peak speeds for flow in the downstream direction varied from 0.5 - 1.0 m/s at all sections. One measurment at Section 5 recorded 1.5 m/s. Peak upstream speeds varied from 0.3 - 0.6 m/s. The greatest, 0.8 m/s, was recorded at Section 6, the section furthest offshore.

The Fraser River flows measured at Hope during the period of field measurements ranged from 4200 - 6150 m^3/s. The average flow at Hope from 1912 - 1979 for each month of the year is presented as a histogram in Plate 2-13. Except during the period of peak floods May through July, the flows are lower than those occurring during the field measurements, and therefore from August through April the current velocities in Canoe Pass would be at the lower end of the ranges measured.

2.4 BATHYMETRY

A detailed bathymetric survey of the Roberts Bank section of Canoe Pass was carried out in September 1980(4). (Plate 2-14)

The survey is plotted to Geodetic Datum which is established by the Geodetic Survey of Canada, and is always approximately Mean Sea Level. Chart Datum is established by the Canadian Hydrographic service and has been defined as the plane of lowest normal tides. The relationship between the two datums varies between locations. At Tsawwassen the difference in elevations between bench marks is approximately 2.9 metres and the difference at Point Atkinson, Vancouver is 3.0 metres. Therefore the Chart Datum is taken as 2.9 metres below Geodetic Datum (approximately Mean Sea Level), for the area of Roberts Bank.

2.5 SCOUR

251 CHANNEL SCOUR

A river or stream flowing around a bend would have secondary circulatory currents occurring in it, primarily at the outside of the bend. These currents can cause erosion of the riverbed if the bed material is soft. This phenomenon is called channel scour.

Channel scour within Canoe Pass across Roberts Bank has been investigated by two hydraulic engineering consultants. Western Canada Hydraulic Laboratory (WCHL)(2) concluded that the maximum point scour depth for the 100 year flood would be 6.18 m, and for the 200 year flood would be 6.5 m measured as the depth below bank full level, (approximately local bank level).

Northwest Hydraulic Consultants Ltd.(3) verified the findings of WCHL. They estimated that the maximum local scour at bends would be 6.5 m below bank full level, and the maximum general degradation would be 0.5 m for a 200 year flood. When combined they gave a maximum point scour of 7.0 m below bank full level which correlated well with the WCHL result.

Additional confirmation was provided by the 1980 bathymetric survey which showed that significant scour holes existed at four points along the length of Canoe Pass. (Plate 2-14.)

	Location Of Scour Hole	Scour Depth (below bank full level)		Length Of Scour Hole
		Average	Max	
1.	Between Brunswick Point and dolphin 1	4.0 m		65 m
2.	Between dolphins 2 and 3	5.5 m		160 m
			6.0 m	25 m
3.	At dolphin 4	4.5 m		20 m
4.	At dolphin 5	4.3 m		40 m
			5.5	10 m

The survey was completed after the 1980 freshet, which was one of the lowest recorded.

Based on these studies, a potential maximum scour depth of 7.0 m has been adopted for the section of the route within or close to the confines of Canoe Pass.

The probability of maximum scour occurring at any particular location is dependent upon the following interrelated factors: flood discharges, tidal variations, bifurcation tendency, regime theory for bends and width/depth ratios, and channel geometry. In the scour analysis of WCHL the probability of all of the above factors was assumed to be equal to 100%.

The conclusion drawn by WCHL was that selection of a pipeline route away from the Canoe Pass Channel would reduce the probability of the maximum scour occurring and that a 5 m burial of the pipe would be adequate for an alignment some distance from the present Canoe Pass Channel. Where the pipeline route runs in Canoe Pass Channel they suggested a minimum cover to the pipeline of 7.0 m below local bank level.

NHCL considered a 90 degree quadrant of Roberts Bank radiating from midchannel opposite Brunswick Point, and defined by lines pointing WNW and SSW to be subject to channelization by Canoe Pass, as shown on Plate 2-15. As a result NHCL considered that maximum scour could occur anywhere within that quadrant.

The NHCL approach is considered to be conservative and a reduction in the probability of maximum scour occurring may be assumed as one moves away from the vicinity of the channel and the centre line of the quadrant. For example, the probability of the channel and the pipeline being coincident during a flood event varies with the distance seaward from Brunswick Point. Near Brunswick Point the two are always coincident and therefore this probability is 100%. At the seaward end the probability of them coinciding is much lower because a major shift in location by Canoe Pass is required. The actual probability is difficult to quantify, as the present state of the art of assessing the individual and the combined effects of the factors previously mentioned is limited.

However, it was concluded that because of this reduced risk of maximum scour occurring, the depth of cover required over the pipeline may be reduced for the section of the route away from the vicinity of the present Canoe Pass Channel and some distance seaward from Brunswick Point. The route and the profile of the pipelines that resulted from these assessments is covered in Section 4.0.

252 WAVE SCOUR

Sediment transported down Canoe Pass is deposited on the foreslope. This nourishment process increases the steepness of the upper foreslope. During a severe storm the slope would be eroded down to a shallower profile by the action of the waves. This wave scour has been analysed by Western Canada Hydraulics Ltd(2). They determined that the flattest slope that the wave cut terrace can assume, would be 0.7 degrees, which is typical of sandy beaches around the world. To prevent this action exposing the pipes, they would be buried 5 m deep in this area.

2.6 CHANNEL MORPHOLOGY

Plate 2-16 shows an aerial photograph of the Canoe Pass section of Roberts Bank and shows conditions at a low tide (-2.5 m GSC) in 1978. The extent of marsh vegetation is clearly visable on the edge of Westham Island and Brunswick Point. The main channel of Canoe Pass is 300-400 m wide and follows an almost straight line across the Bank in a southwest direction. There are two secondary channels that branch from the main arm. The first flows away to the south on a meandering course, from a point half way across the flats. The second flows to the northwest from a point approximately two thirds the way across the flats. The main and secondary channels become shallower and broader as they approach the edge of the foreslope. This shoaling extends over the last 1.5 kilometres of the main channel. The shoaling is caused by the build up of sediment which is dropped out of suspension as the velocity in the channel reduces on entering the Strait of Georgia. The channel broadens in order to continue to carry the same flow.

The position of Canoe Pass channel was plotted on Plates 2-17 to 2-19 from old aerial photographs and surveys for various years between 1950 and 1980 as follows:

Plate 2-17	1950	Low tide - 2.3 m GSC
Plate 2-18	1975	Low tide - 2.2 m GSC
Plate 2-19	1980	Bathymetric survey

The plates were prepared as transparencies to permit them to be compared with the 1978 photo mosaic of the Canoe Pass area of Roberts Bank (Plate 2-16).

The overlays show that the location of the first three kilometres of Canoe Pass seawards of Brunswick Point have not varied significantly during the period. This is attributed to the more stable channel banks created by the tidal marsh at Westham Island and Brunswick Point.

Across the outer section of the banks, Canoe Pass has followed a number of different routes. Since about 1975, a channel close to the centre of the delta, which flows to the southwest, has dominated the system, as shown in Plates 2-16 and 2-18. An alignment of the main channel at the centre of the delta is likely to be persistent as this course gives the steepest slope of the water surface.

TABLE 2-1

Monthly Distribution of Significant Wave Height

Offshore Roberts Bank Recorded 1974-6

	1974		1975		1976			
	Monthly Mean Hs (m)	Monthly Max Hs (m)	Monthly Mean Hs (m)	Monthly Max Hs (m)	Monthly Mean Hs (m)	Monthly Max Hs (m)	Average Mean (m)	Average Max (m)
JAN	--	--	--	--	0.3	1.1	0.3	1.1
FEB	0.5	1.4	--	--	0.4	1.2	0.5	1.3
MARCH	0.4	1.6	--	--	0.4	1.9	0.4	1.8
APRIL	0.4	0.9	0.4	1.6	--	--	0.4	1.3
MAY	--	--	0.3	2.2	--	--	0.3	2.2
JUNE	0.3	1.3	0.3	1.3	--	--	0.3	1.3
JULY	0.3	1.0	0.2	1.4	--	--	0.3	1.2
AUGUST	0.2	1.2	0.3	1.0	--	--	0.3	1.1
SEPT	0.2	1.5	0.3	1.2	--	--	0.3	1.4
OCT	0.3	1.3	0.4	1.4	--	--	0.4	1.4
NOV	--	--	0.5	1.9	--	--	0.5	1.9
DEC	--	--	0.4	1.6	--	--	0.4	1.6

TABLE 2-2

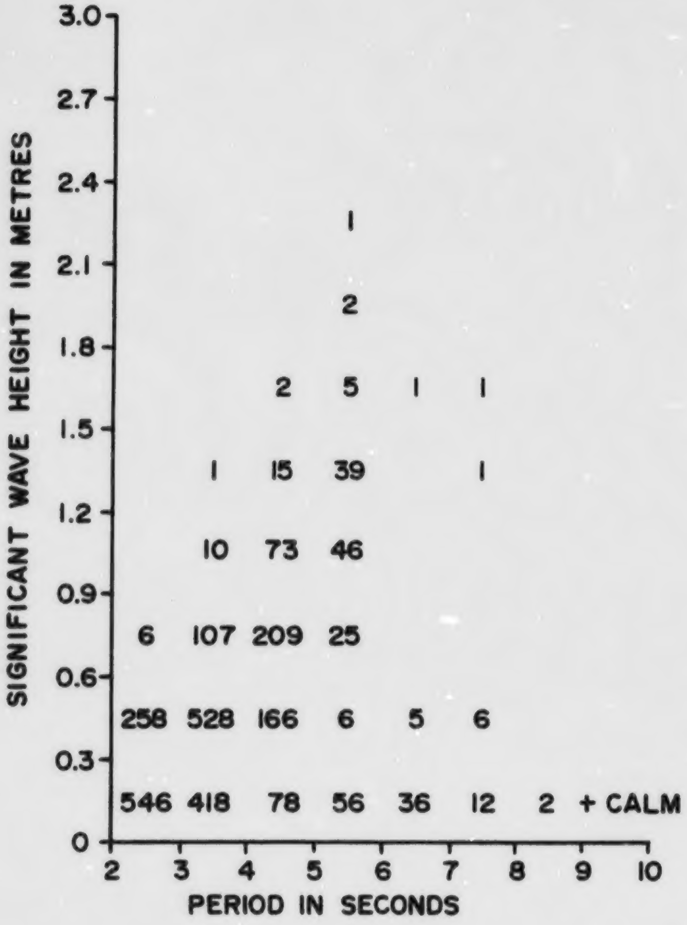
Highest Hindcast Wave and Peak Period By Direction

Offshore Roberts Bank

Length of Record of Winds = 10 yrs.

Direction (True)	Significant Wave Height (m)	Peak Period (sec)	Number hindcast in ten yrs.	Return period years
N	0.92	4	1	10
NE	0.61	3	2	5
E	0.92	4	5	2
SE	2.44	7	2	5
S	1.83	6	2	2
SW	1.53	5	1	10
W	1.83	6	6	1.67
NW	3.36	9	1	10

ROBERTS BANK, B.C.
FEBRUARY 7, 1974 TO APRIL 3, 1976.
NUMBER OF OBSERVATIONS 3880
OCCURENCES OF CALM 1219



% 3 Hourly Records	% Exceedance
0.03	0.04
0.05	0.09
0.23	0.32
1.44	1.76
3.32	5.08
8.94	14.02
24.97	38.99
61.01	100.00

PLATE 2-1

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

SIGNIFICANT WAVE HEIGHT PERIOD SCATTER DIAGRAM STATION 108

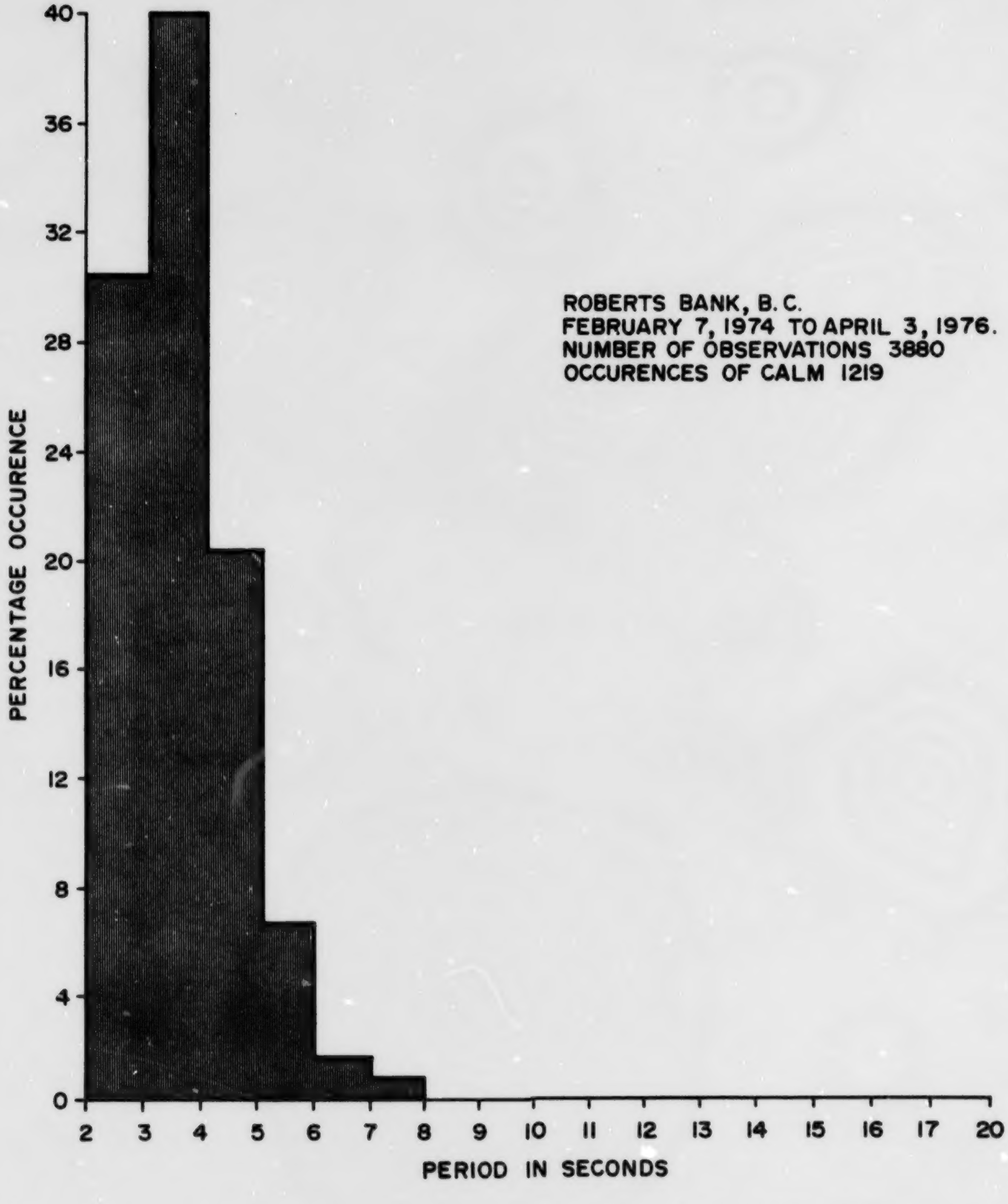


PLATE 2-2

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

SIGNIFICANT WAVE
PERIOD HISTOGRAM
STATION 108

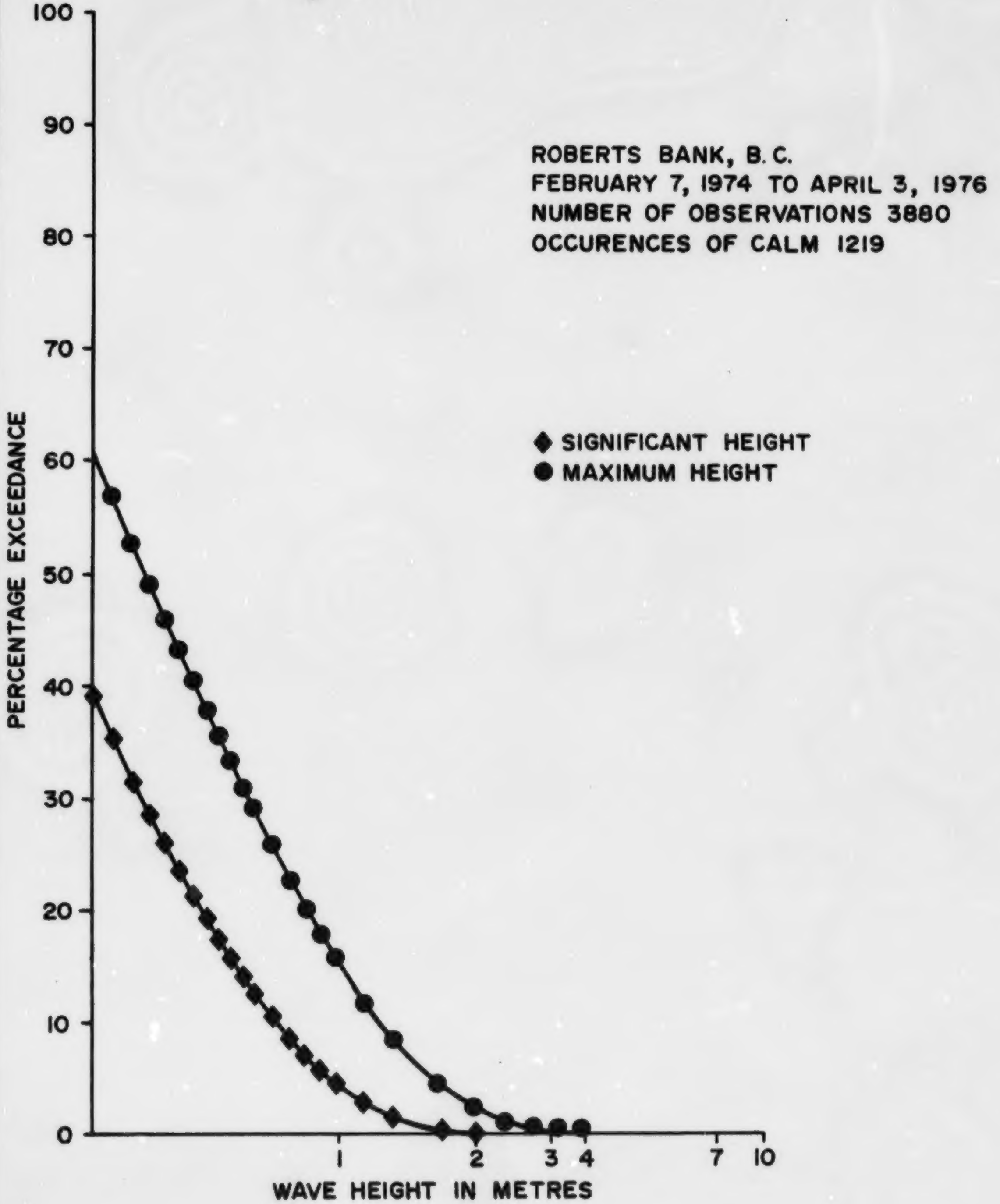
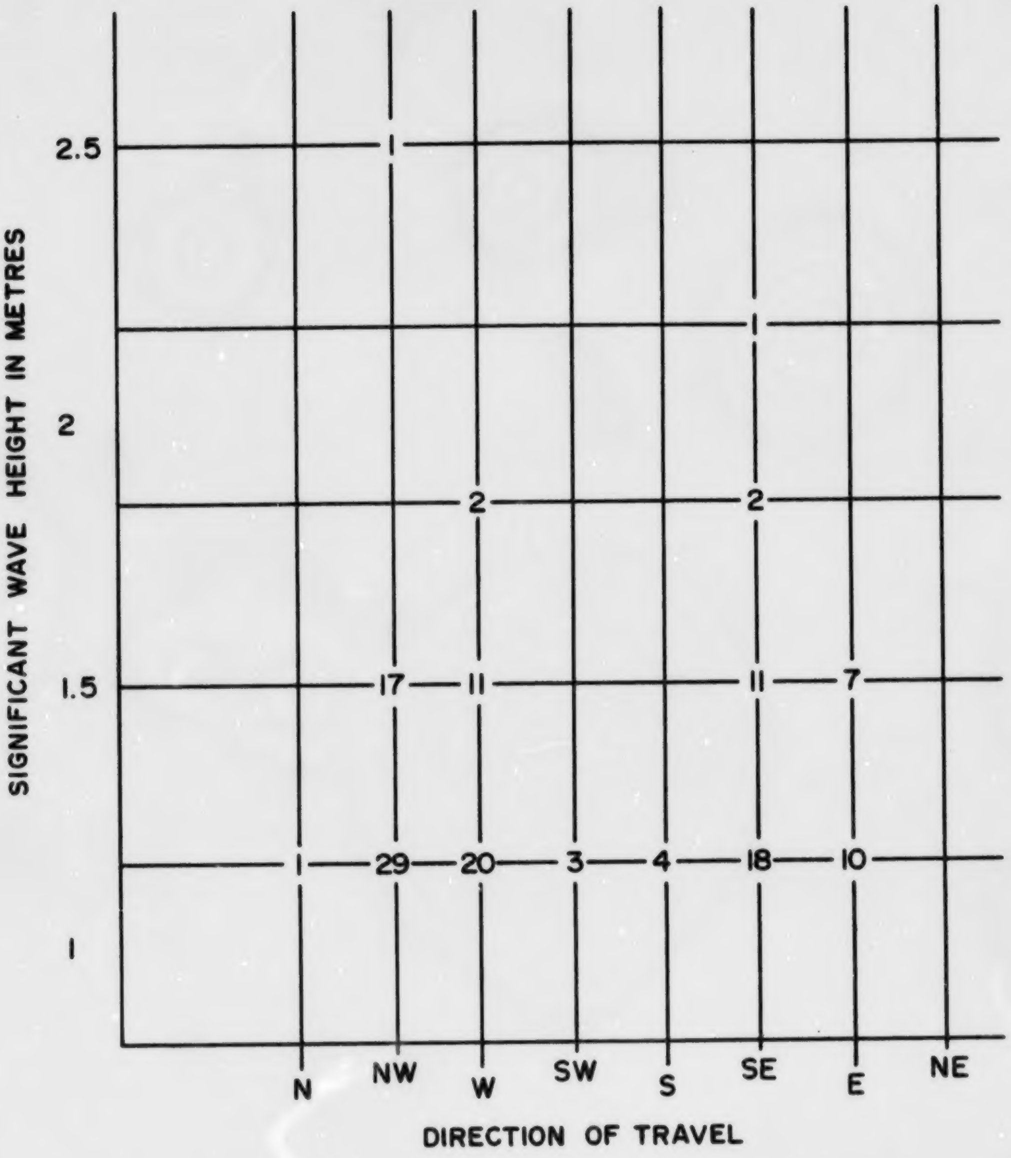


PLATE 2-3

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

SIGNIFICANT WAVE HEIGHT EXCEEDANCE DIAGRAM STATION 108

MONENCO PIPELINE CONSULTANTS LTD.



TOTAL 137 CASES

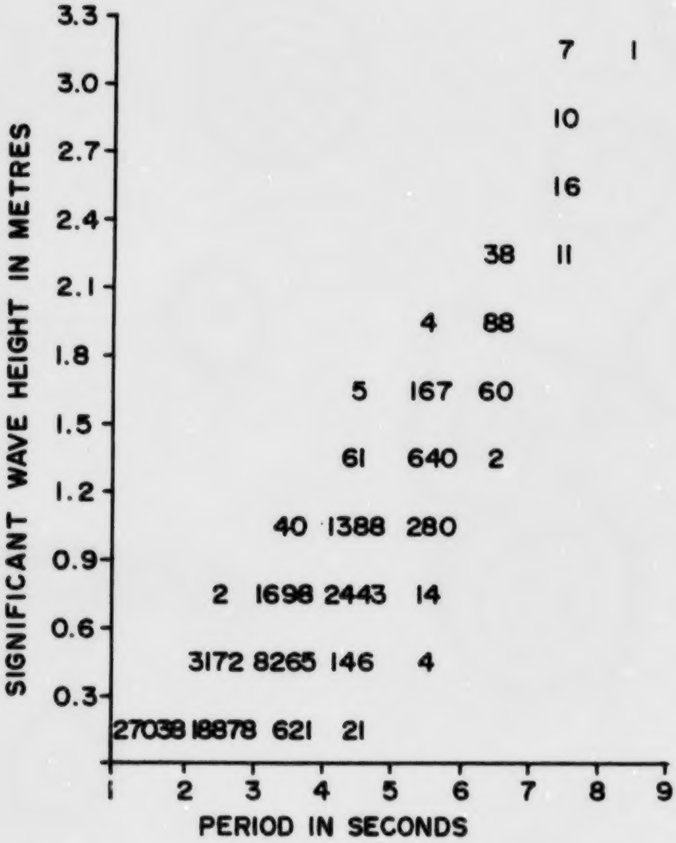
PLATE 2-4

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

SIGNIFICANT WAVE HEIGHT DIRECTION SCATTER DIAGRAM FOR OFFSHORE ROBERTS BANK

MONENCO PIPELINE CONSULTANTS LTD.

WIND DATA RECORDED AT SANDHEADS
MAY 1967 - APRIL 1977
NUMBER OF HOURLY RECORDS 87439
OCCURENCES OF CALM (ASSUMED) 22319

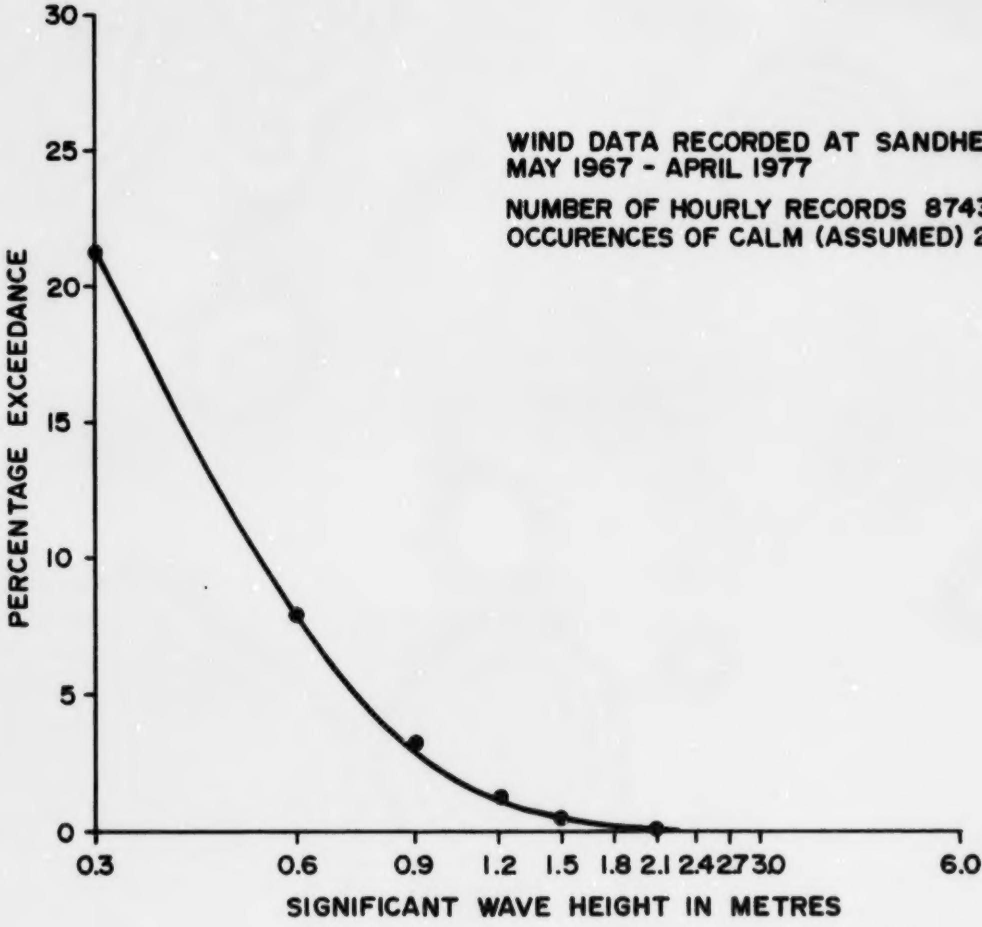


% Hourly Records	% Exceedance
0.0090	0.0103
0.0114	0.0217
0.0183	0.0400
0.056	0.096
0.105	0.201
0.265	0.466
0.804	1.270
1.953	3.223
4.754	7.977
13.252	21.229
78.771	100.00

PLATE 2-5

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

HINDCAST SIGNIFICANT WAVE HEIGHT PERIOD SCATTER DIAGRAM FOR OFFSHORE ROBERTS BANK



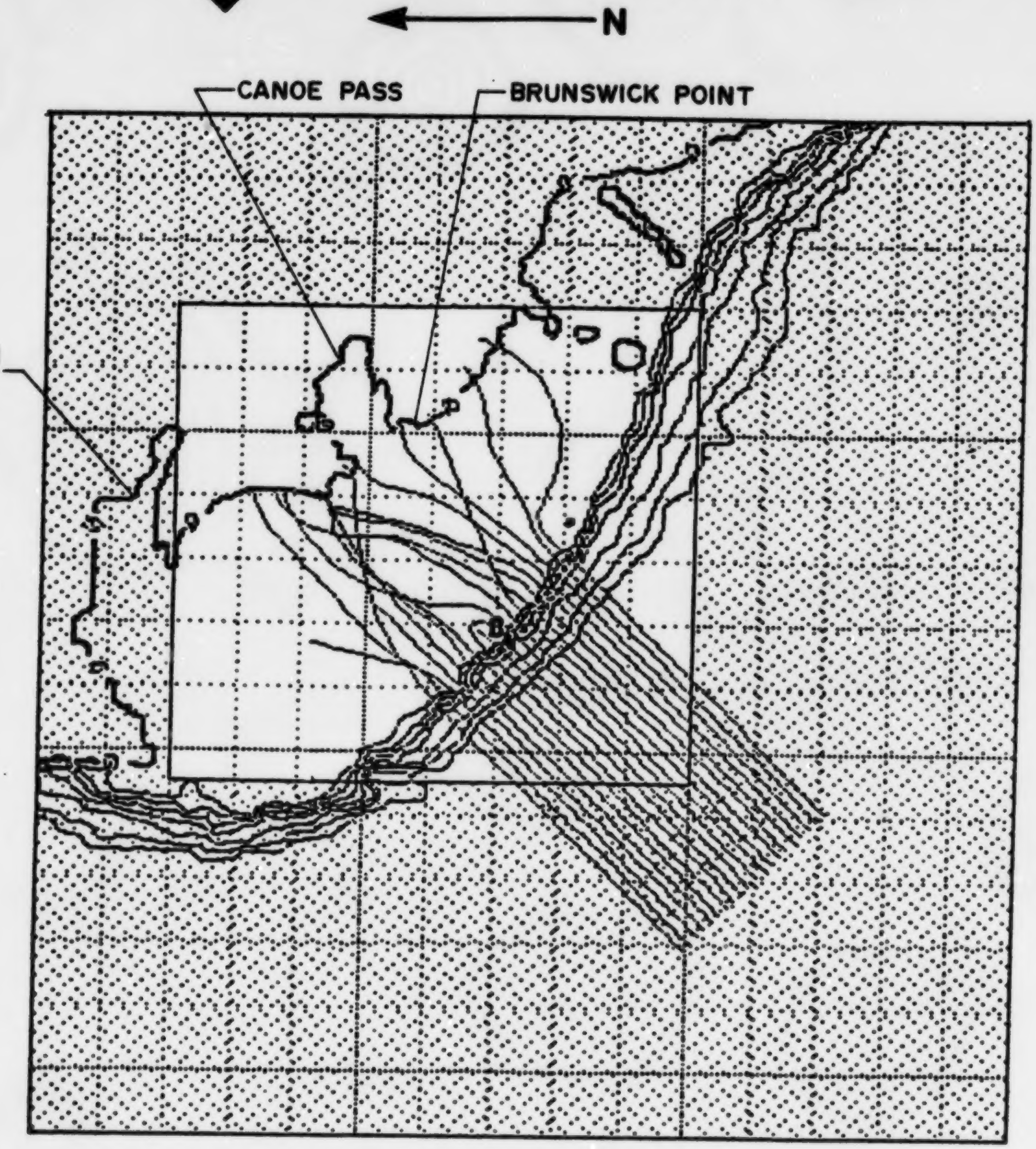
WIND DATA RECORDED AT SANDHEADS
MAY 1967 - APRIL 1977

NUMBER OF HOURLY RECORDS 87439
OCCURENCES OF CALM (ASSUMED) 22319

PLATE 2-6

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

HINDCAST SIGNIFICANT WAVE HEIGHT
EXCEEDANCE DIAGRAM
FOR OFFSHORE ROBERTS BANK


N
CANOE PASS
BRUNSWICK POINT
SOUTH ARM

WATER LEVEL = + 3.0 m
WAVE PERIOD = 8 sec.
1 GRID INTERVAL = 5000 distance units

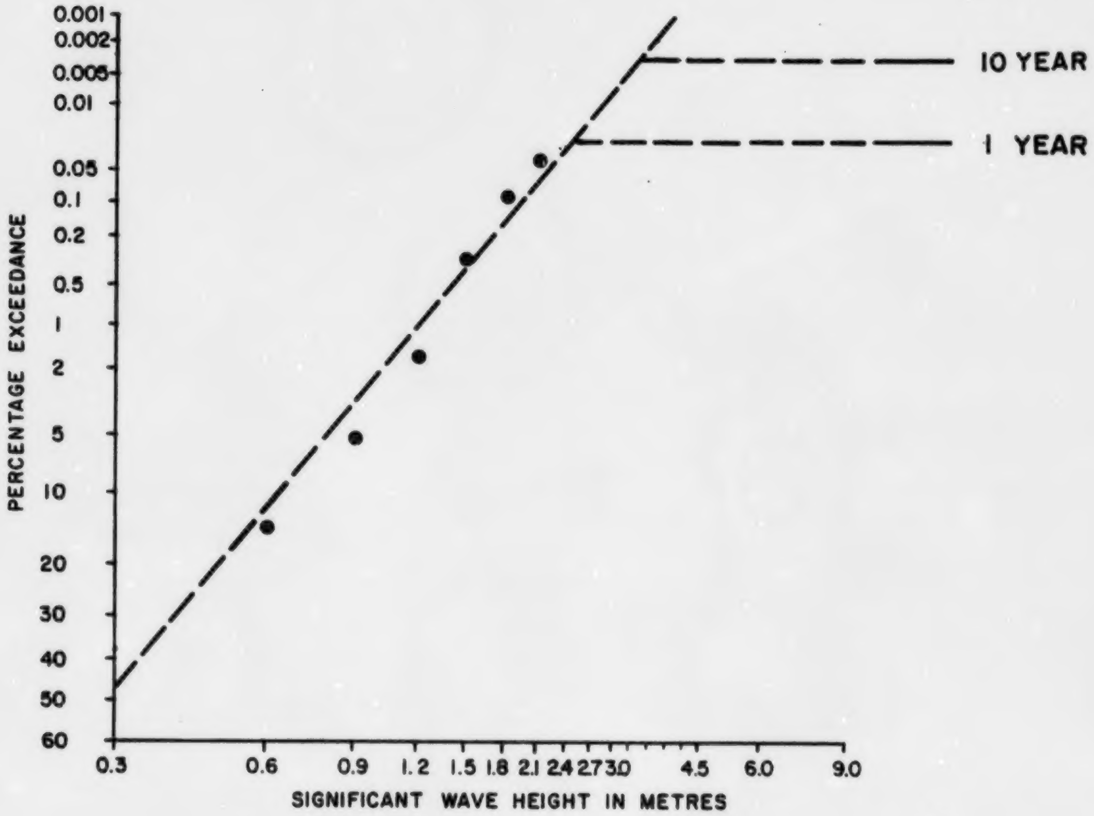
REFERENCE: (1)

PLATE 2-7

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

EXAMPLE OF WAVE REFRACTION
ROBERTS BANK

RECORDING
INTERVAL
3 HOURS



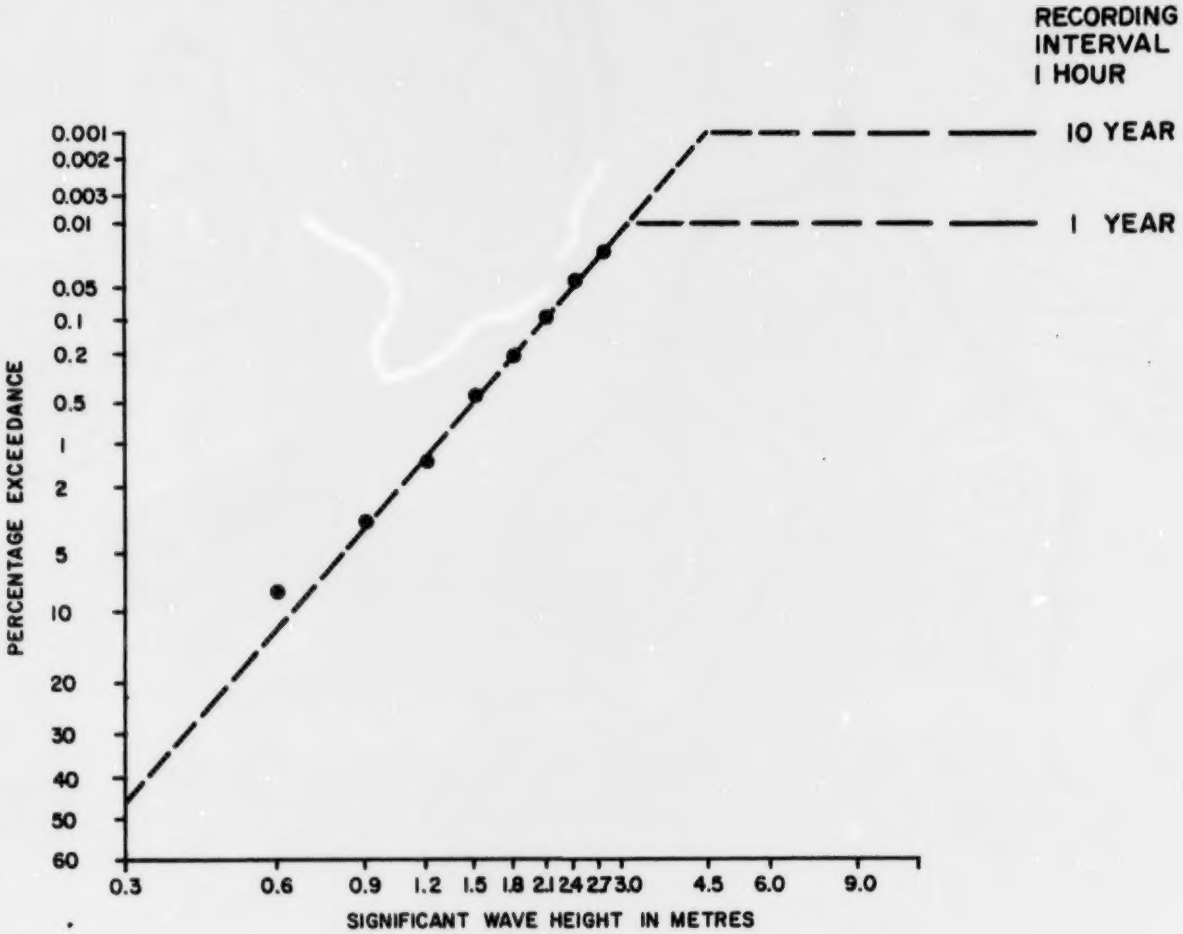
WEIBULL
DISTRIBUTION

MAXIMUM H_S IN 2 YEARS
OF RECORDS 2.16 m.

PLATE 2-8

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

EXCEEDANCE DIAGRAM
RECORDED WAVES
FOR OFFSHORE ROBERTS BANK



WEIBULL
DISTRIBUTION

MAXIMUM H_S IN 10 YEARS
OF HINDCAST RESULTS 3.0 - 3.3m

PLATE 2-9

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

EXCEEDANCE DIAGRAM HINDCAST WAVES FOR OFFSHORE ROBERTS BANK

MONENCO PIPELINE CONSULTANTS LIMITED

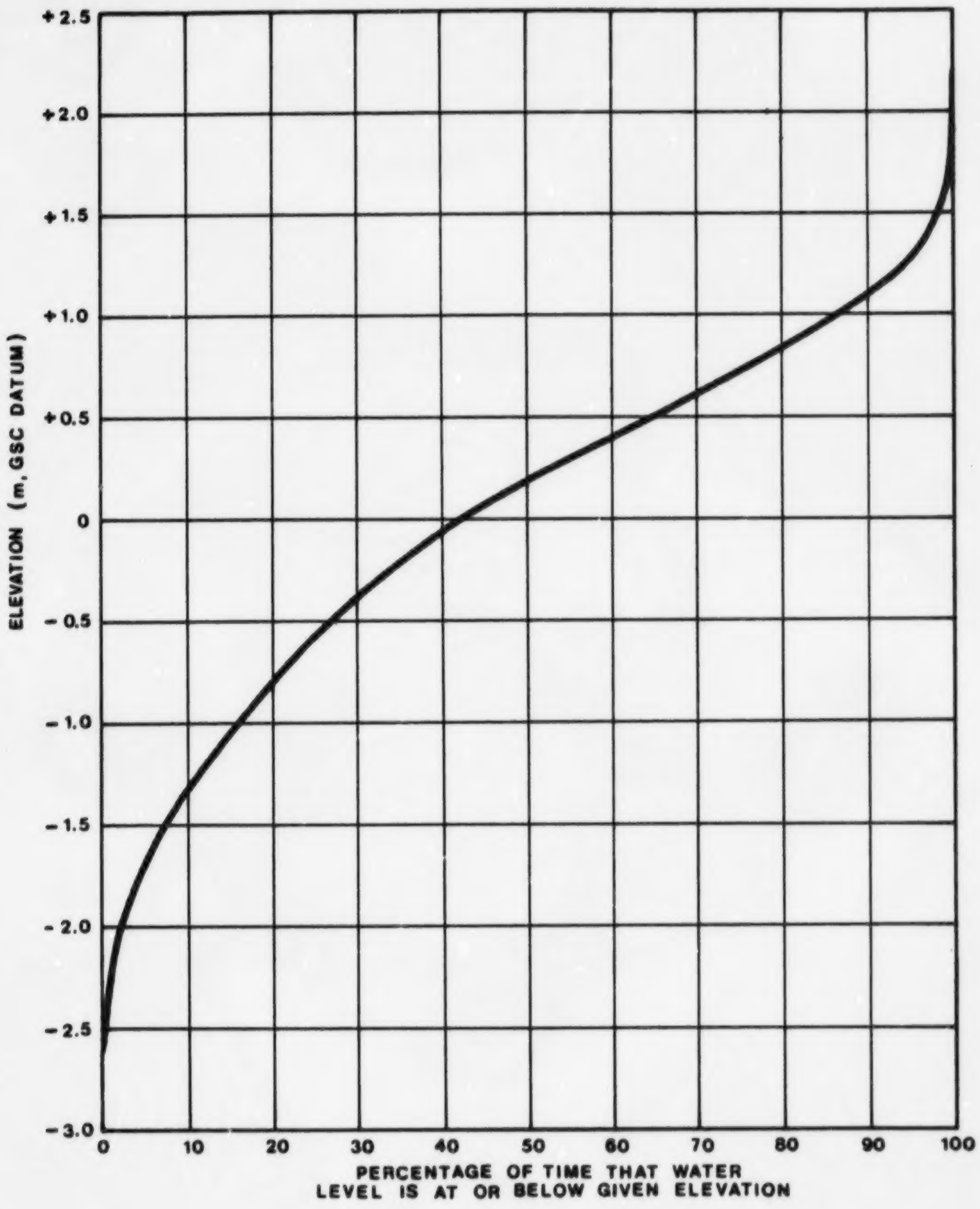
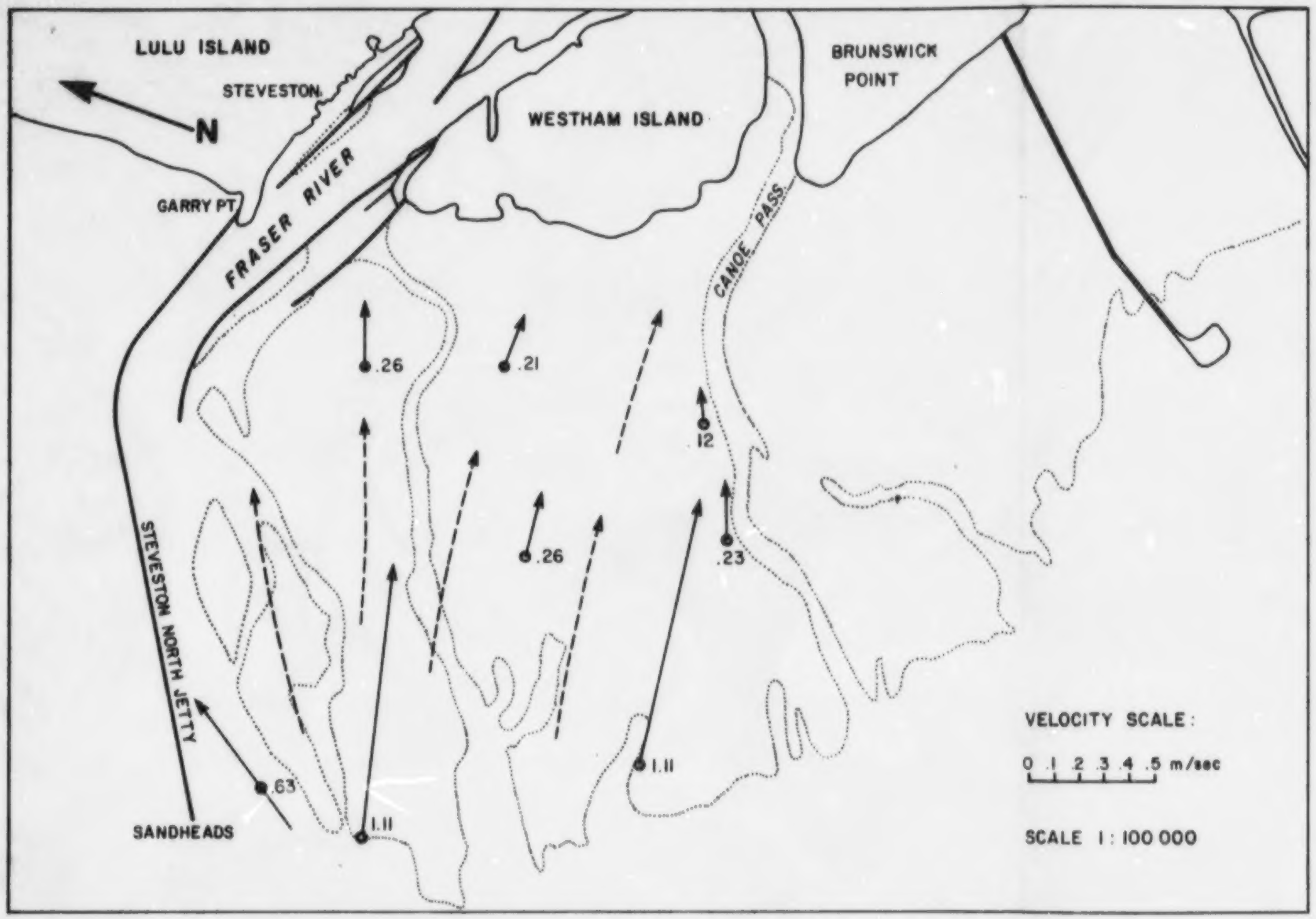


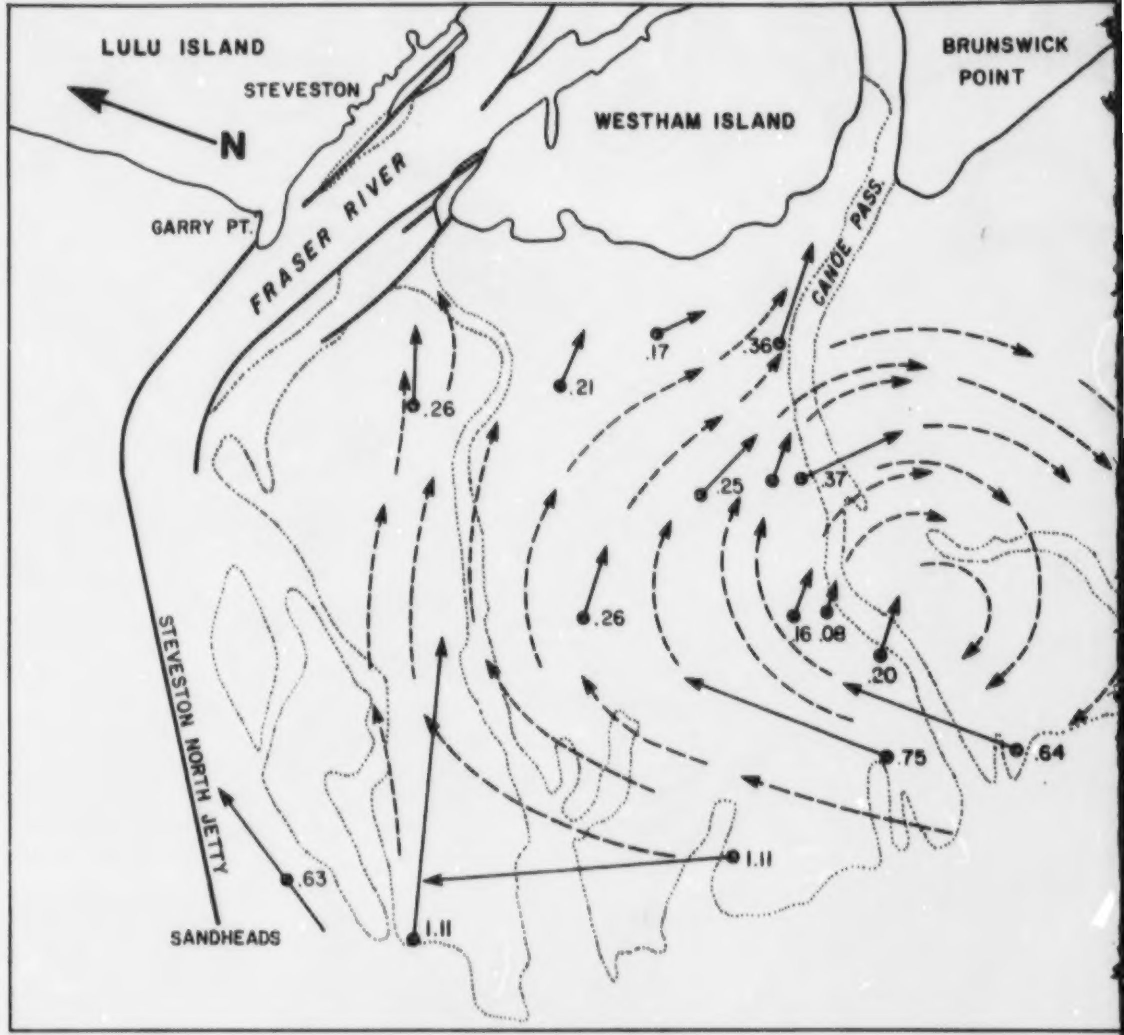
PLATE 2-10

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

OBSERVED OCCURRENCE OF WATER LEVELS AT TSAWWASSEN, B.C. 1977


LULU ISLAND
STEVESTON
N
GARRY PT
FRASER RIVER
WESTHAM ISLAND
BRUNSWICK POINT
CANOE PASS
.26
.21
.12
.26
.23
STEVESTON NORTH JETTY
.63
1.11
1.11
SANDHEADS
VELOCITY SCALE:
0 .1 .2 .3 .4 .5 m/sec
SCALE 1 : 100 000

EARLY FLOOD TIDE OCTOBER 19, 1979


LULU ISLAND
STEVESTON
N
GARRY PT.
FRASER RIVER
WESTHAM ISLAND
BRUNSWICK POINT
CANOE PASS
.26
.21
.17
.36
.25
.37
.26
.16
.08
.20
.75
.64
STEVESTON NORTH JETTY
.63
1.11
1.11
SANDHEADS

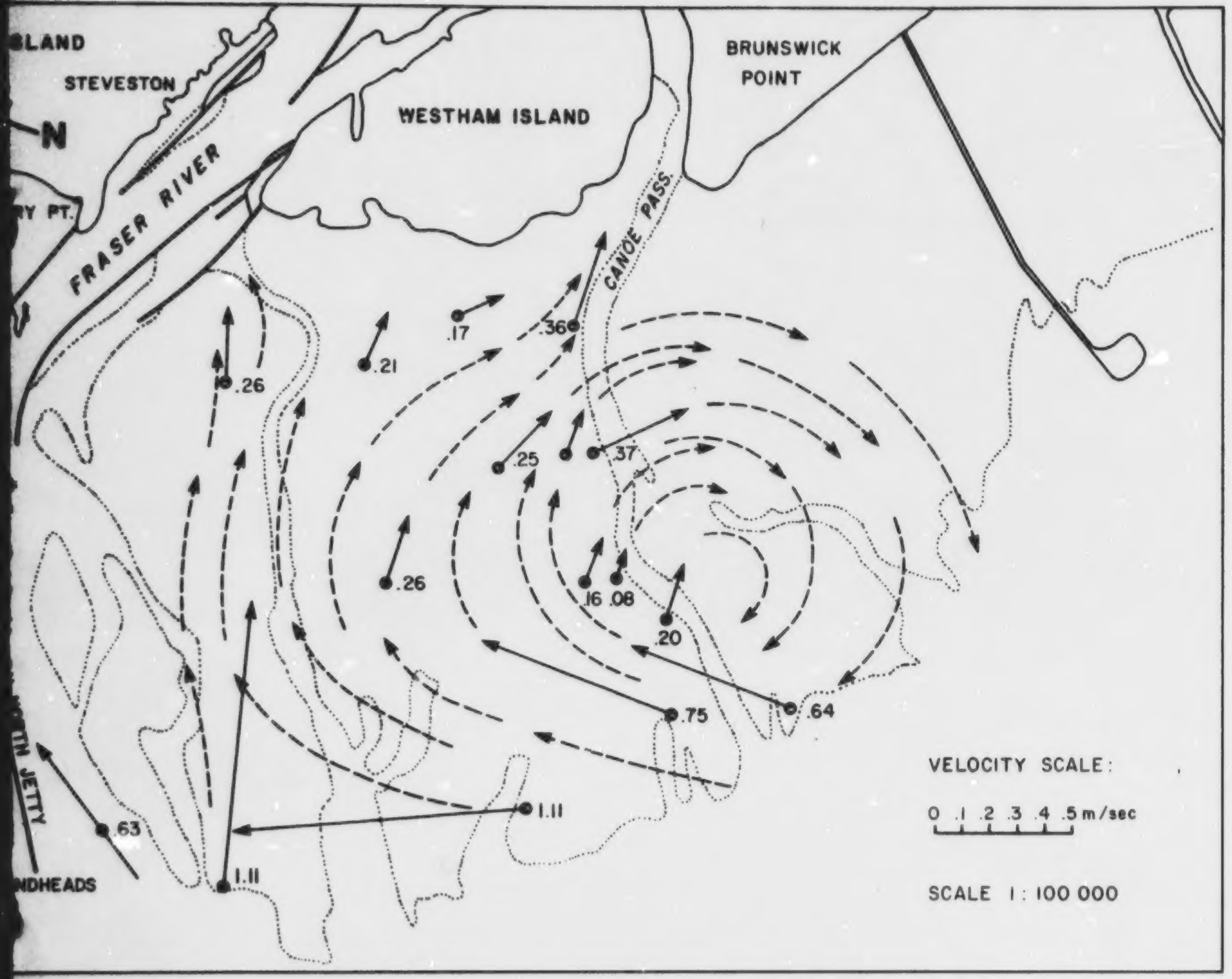
STRONG, LATE FLOOD TIDE OCTOBER, 1979

LEGEND

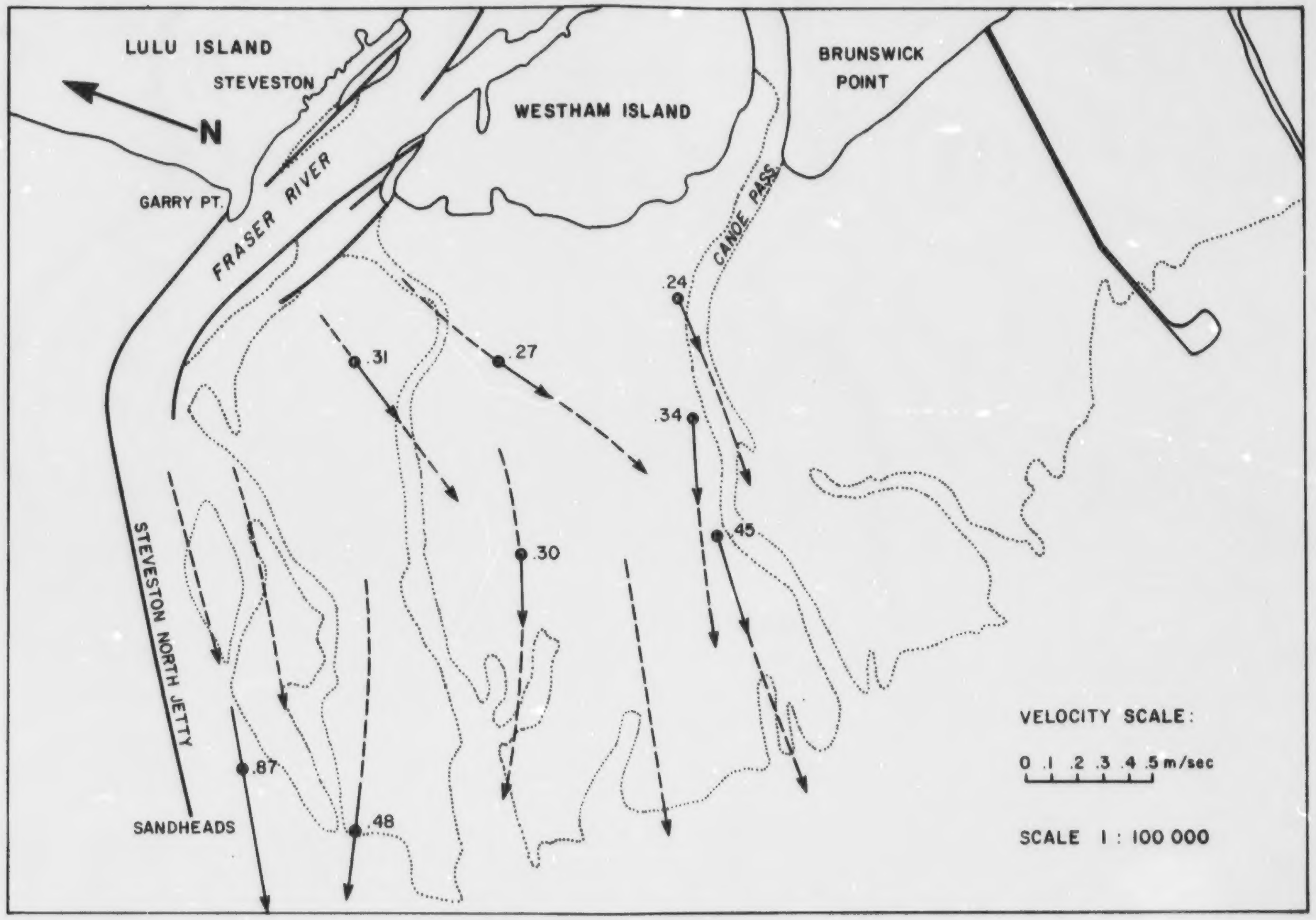
●—.3→ RECORDED CURRENT VECTOR

- - → GENERAL FLOW DIRECTION

MONENCO PIPELINE CONSULTANTS LTD.


SLAND
STEVESTON
N
WESTHAM ISLAND
BRUNSWICK
POINT
RY PT.
FRASER RIVER
CANOE PASS
.26
.21
.17
.36
.25
.37
.26
.16
.08
.20
.75
.64
1.11
1.11
.63
TH JETTY
NDHEADS
VELOCITY SCALE:
0 .1 .2 .3 .4 .5 m/sec
SCALE 1 : 100 000

STRONG, LATE FLOOD TIDE OCTOBER, 1979


LULU ISLAND
STEVESTON
N
WESTHAM ISLAND
BRUNSWICK
POINT
GARRY PT.
FRASER RIVER
CANOE PASS
.24
.31
.27
.34
.30
.45
.87
.48
STEVESTON NORTH JETTY
SANDHEADS
VELOCITY SCALE:
0 .1 .2 .3 .4 .5 m/sec
SCALE 1 : 100 000

EBB TIDE OCTOBER 19, 1979

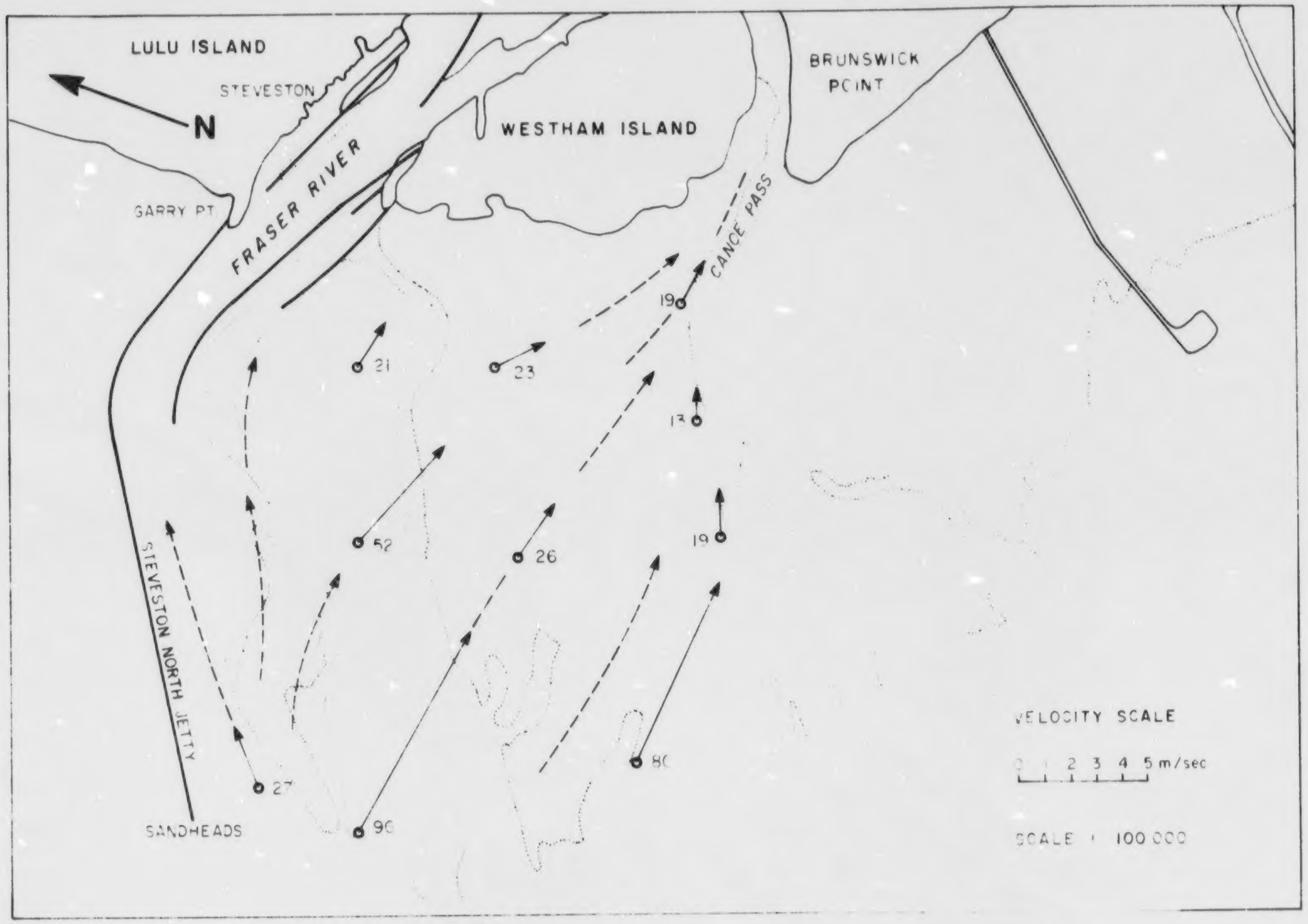
PLATE 2-11

B.C. HYDRO AND POWER AUTHORITY

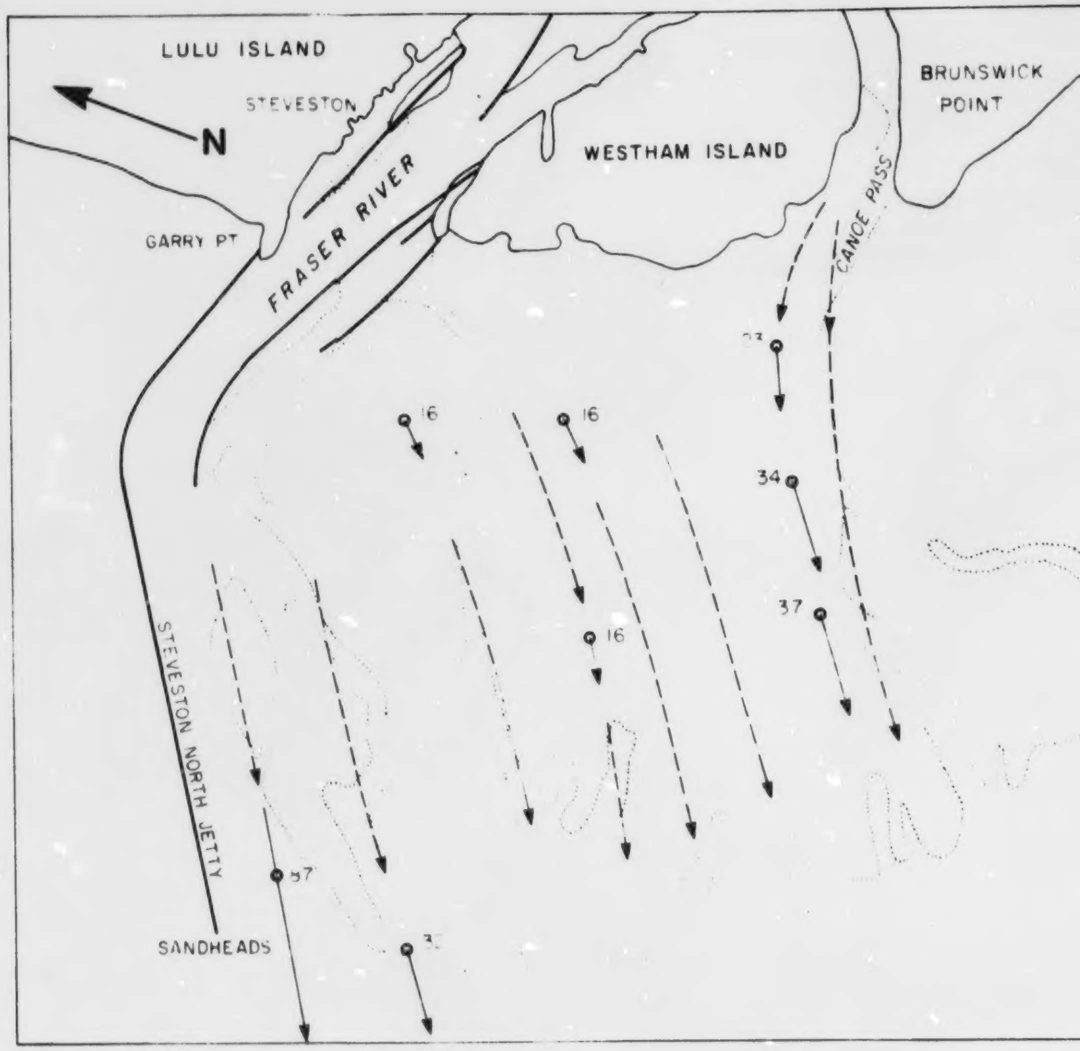
ROBERTS BANK

RECORDED SURFACE CURRENTS

MONENCO PIPELINE CONSULTANTS LTD.


LULU ISLAND
STEVESTON
N
GARRY PT
FRASER RIVER
WESTHAM ISLAND
BRUNSWICK POINT
CANOE PASS
19
21
23
13
52
26
19
STEVESTON NORTH JETTY
27
96
80
SANDHEADS
VELOCITY SCALE
0 1 2 3 4 5 m/sec
SCALE 1:100 000

EARLY FLOOD TIDE OCTOBER 19, 1979


LULU ISLAND
STEVESTON
N
GARRY PT
FRASER RIVER
WESTHAM ISLAND
BRUNSWICK POINT
CANOE PASS
23
16
16
34
37
16
STEVESTON NORTH JETTY
37
SANDHEADS

EBB TIDE OCTOBER 19, 1979

LEGEND

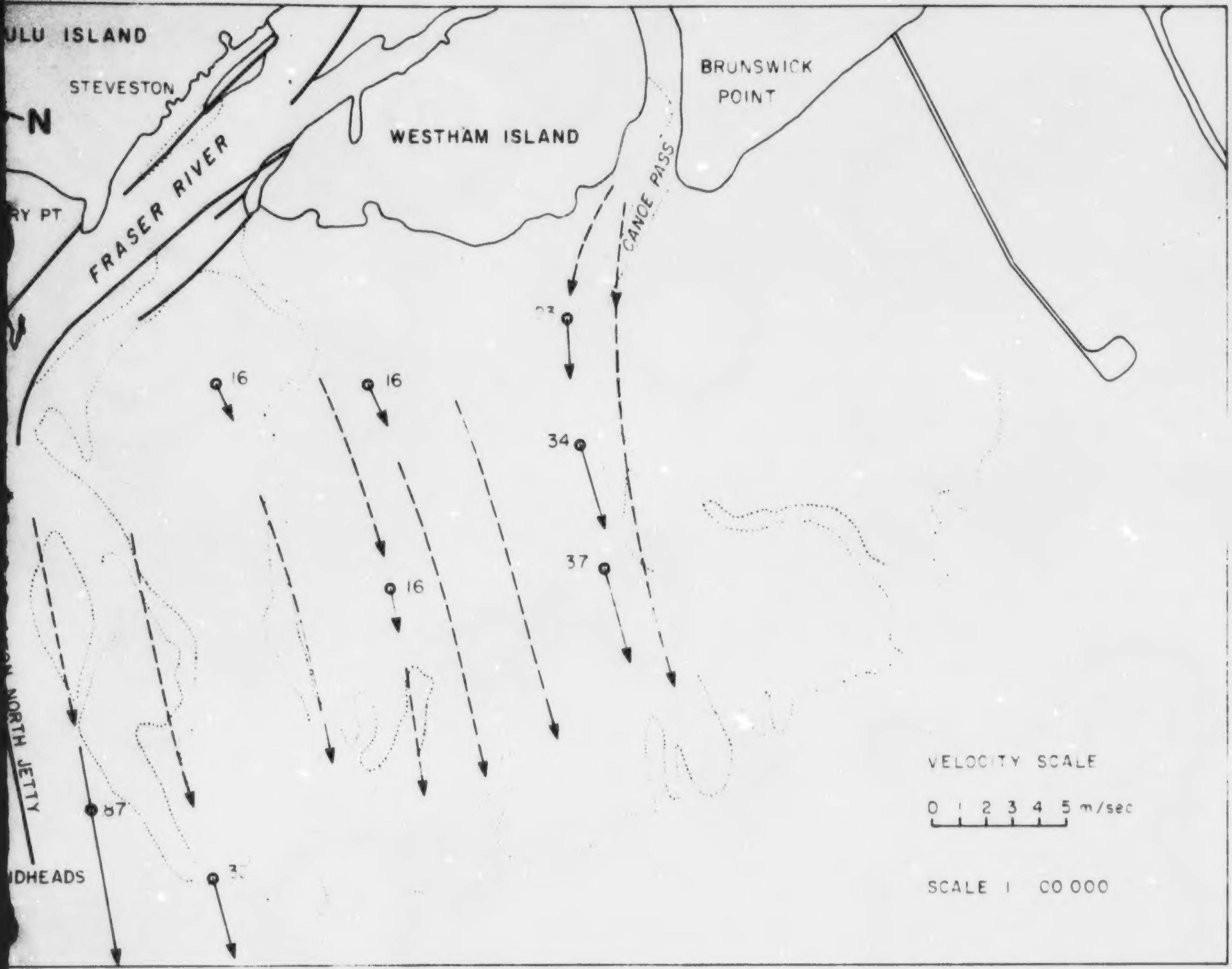
○—.5—→ RECORDED CURRENT VECTOR

– – – → GENERAL FLOW DIRECTION

B.C.

RECOR

ULTANTS LTD.


ULU ISLAND
STEVESTON
N
FRASER RIVER
RY PT
WESTHAM ISLAND
BRUNSWICK POINT
CANOE PASS
16
16
23
34
37
16
87
3
NORTH JETTY
DHEADS
VELOCITY SCALE
0 1 2 3 4 5 m/sec
SCALE 1 00 000

EBB TIDE OCTOBER 19, 1979

PLATE 2-12

B.C. HYDRO AND POWER AUTHORITY

ROBERTS BANK

RECORDED BOTTOM CURRENTS

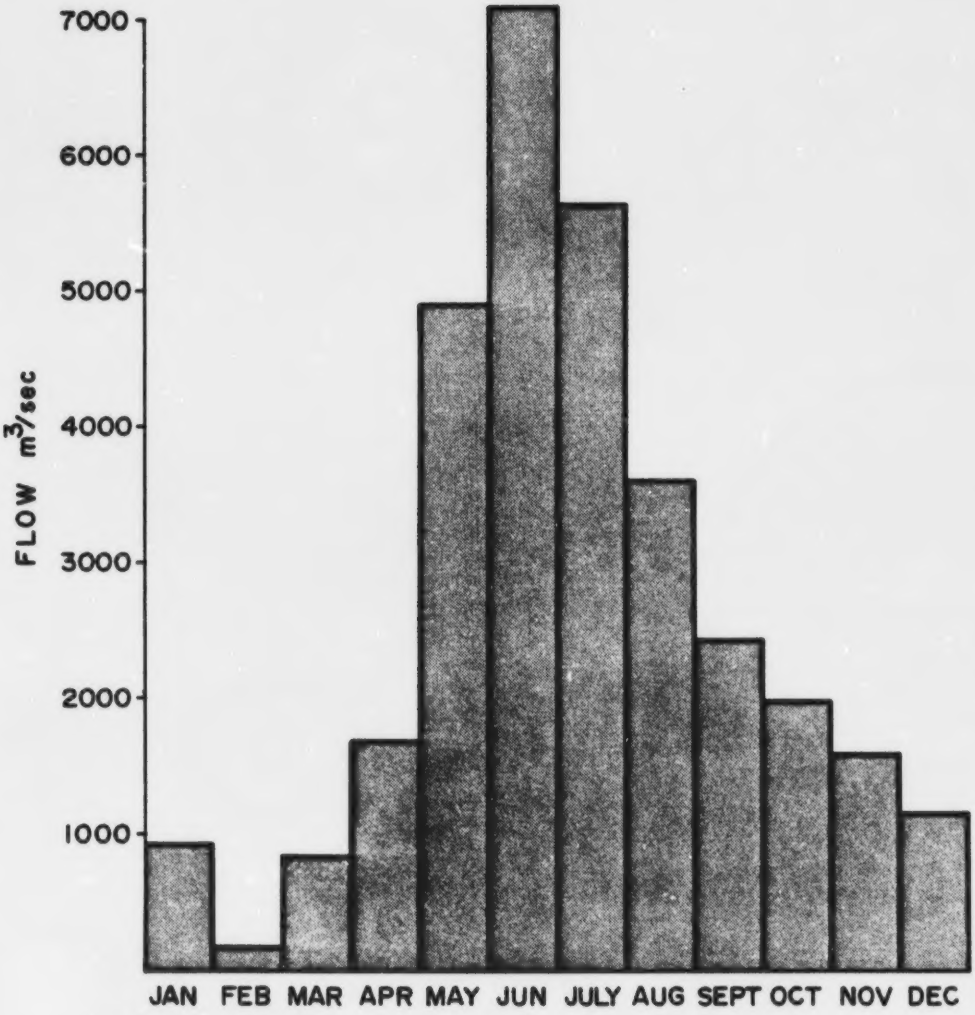


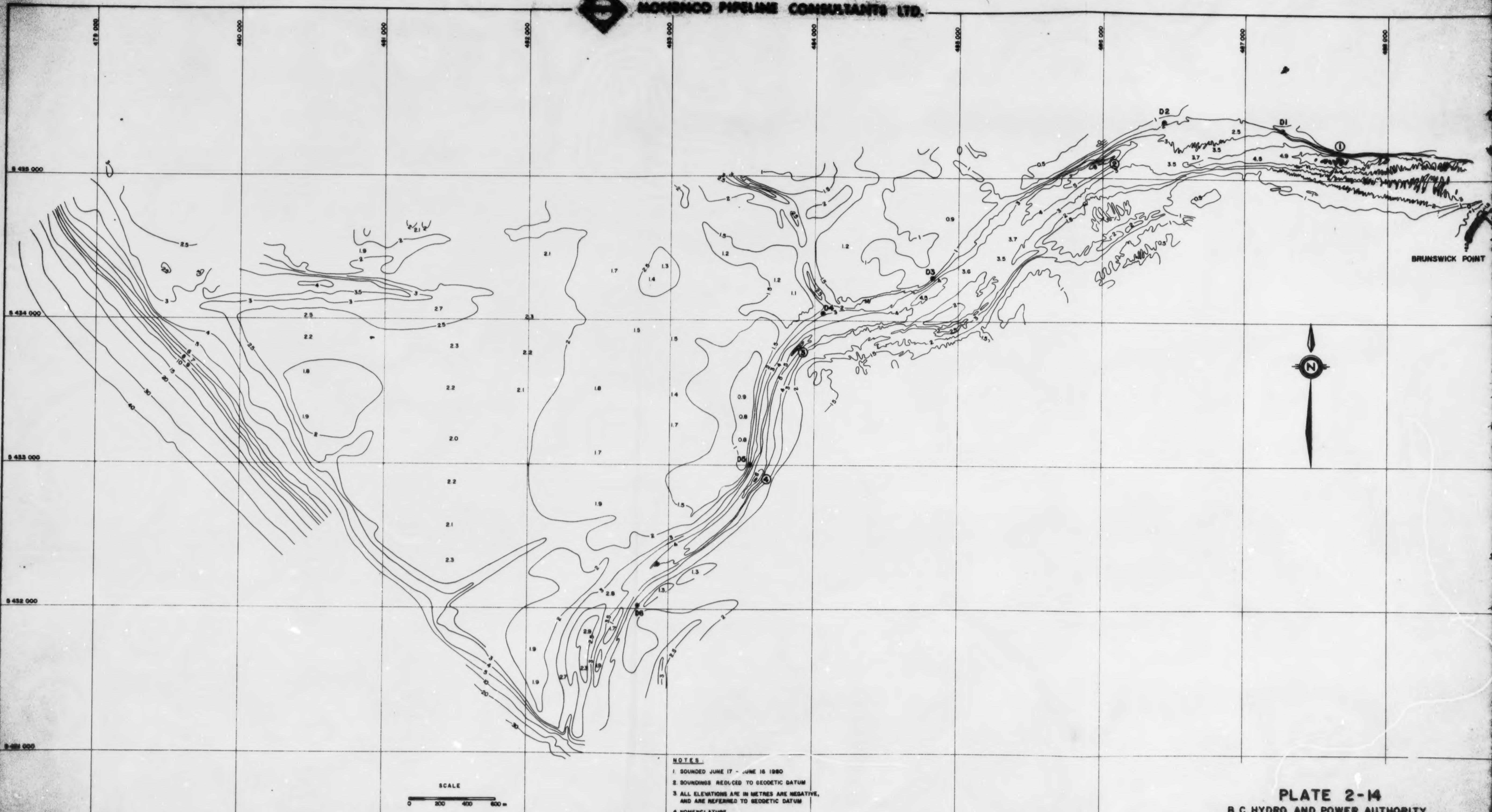
PLATE 2-13

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

AVERAGE FLOWS OF FRASER RIVER
AT HOPE B.C.

(BASED ON RECORDS 1912 - 1979)

MONENCO PIPELINE CONSULTANTS LTD.


479 000
480 000
481 000
482 000
483 000
484 000
485 000
486 000
487 000
488 000
5 435 000
5 434 000
5 433 000
5 432 000
5 431 000
D1
D2
D3
D4
D5
D6
①
②
③
④
BRUNSWICK POINT
N
SCALE
0
200
400
600 m

NOTES:

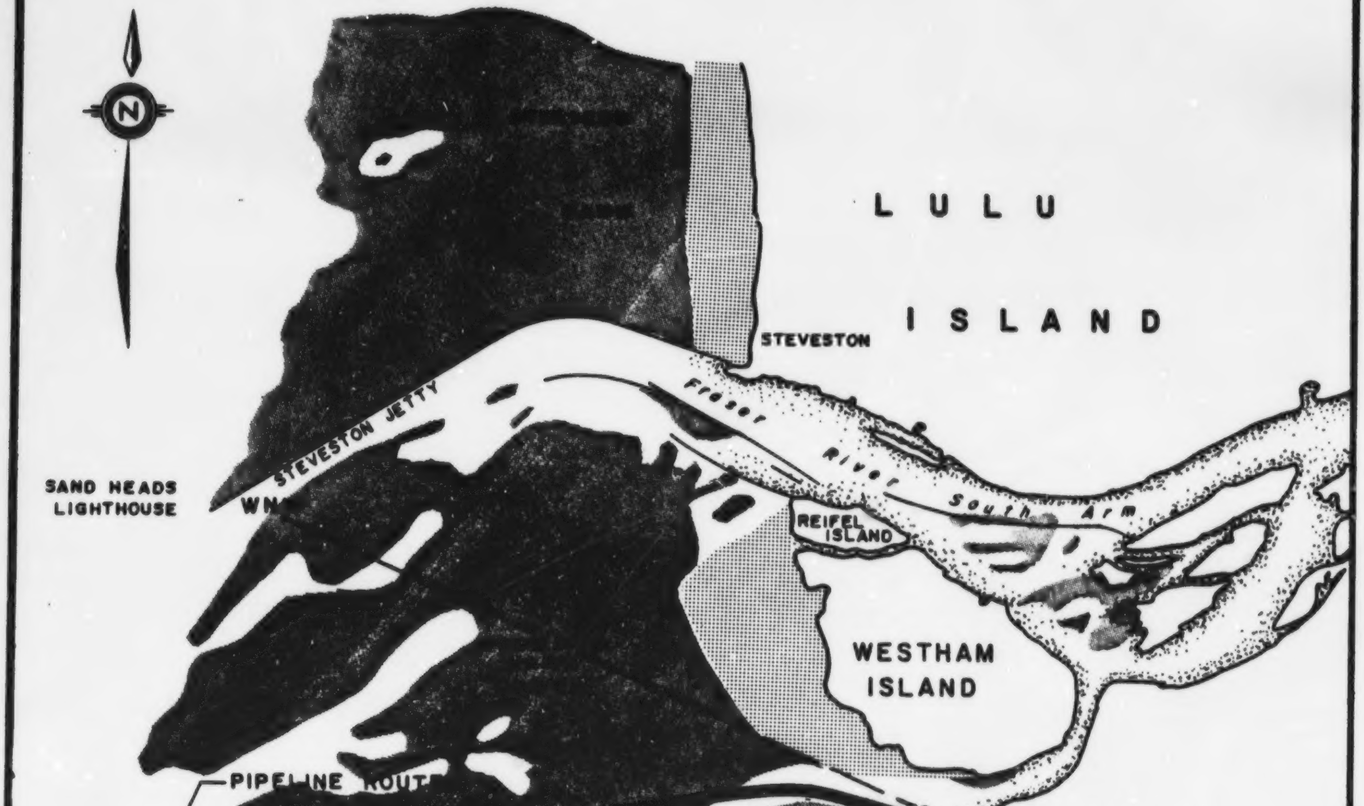
1. SOUNDED JUNE 17 - JUNE 18 1980
2. SOUNDINGS REDUCED TO GEODETIC DATUM
3. ALL ELEVATIONS ARE IN METRES ARE NEGATIVE, AND ARE REFERRED TO GEODETIC DATUM
4. NOMENCLATURE
   "D4" DESIGNATES DOLPHIN LOCATION
   ② DESIGNATES SEEP SCOUR HOLE LOCATION

PLATE 2-14

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

1980 BATHYMETRY SURVEY

MONENCO PIPELINE CONSULTANTS LTD.


N
LULU ISLAND
STEVESTON
STEVESTON JETTY
Fraser River South Arm
SAND HEADS LIGHTHOUSE
WN
REIFEL ISLAND
WESTHAM ISLAND
PIPELINE ROUTE
BRUNSWICK POINT
DELTA
Canoe Passage
CABLE AREA
OUTLINE EXPANSION 1981 / 82
SSW
WESTSHORE COAL TERMINAL
TSAWWASSEN FERRY TERMINAL
CANADA
UNITED STATES OF AMERICA
BRITISH COLUMBIA
WASHINGTON

LEGEND

▨ TIDAL MARSH

■ INTERTIDAL FLATS

PLATE 2-15

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT
ROBERTS BANK
AREA SUBJECT TO CHANNELIZATION
BY CANOE PASS

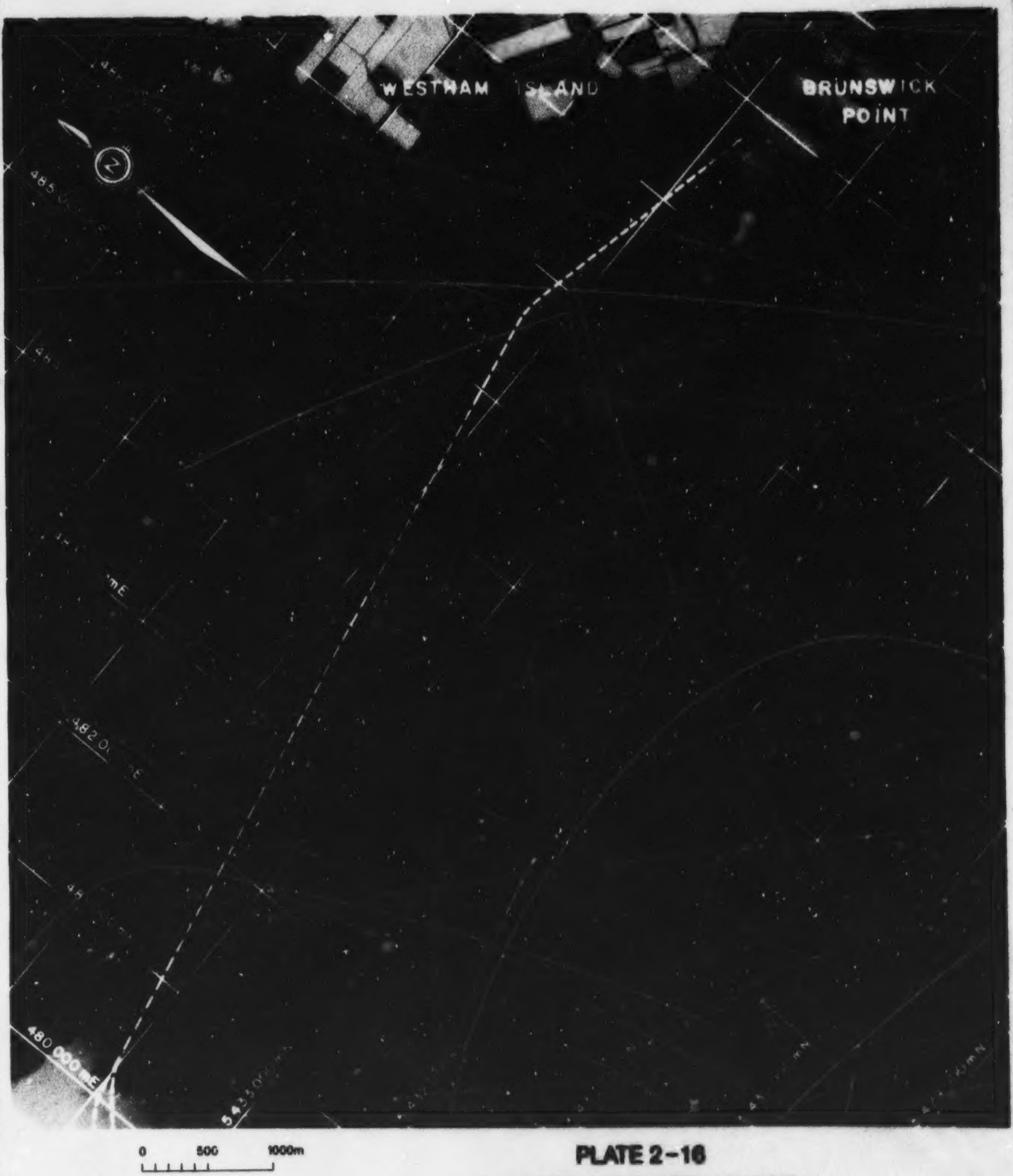

WESTHAM ISLAND
BRUNSWICK POINT
485 000 mE
482 000 mE
480 000 mE
5433 000 mN
0
500
1000m

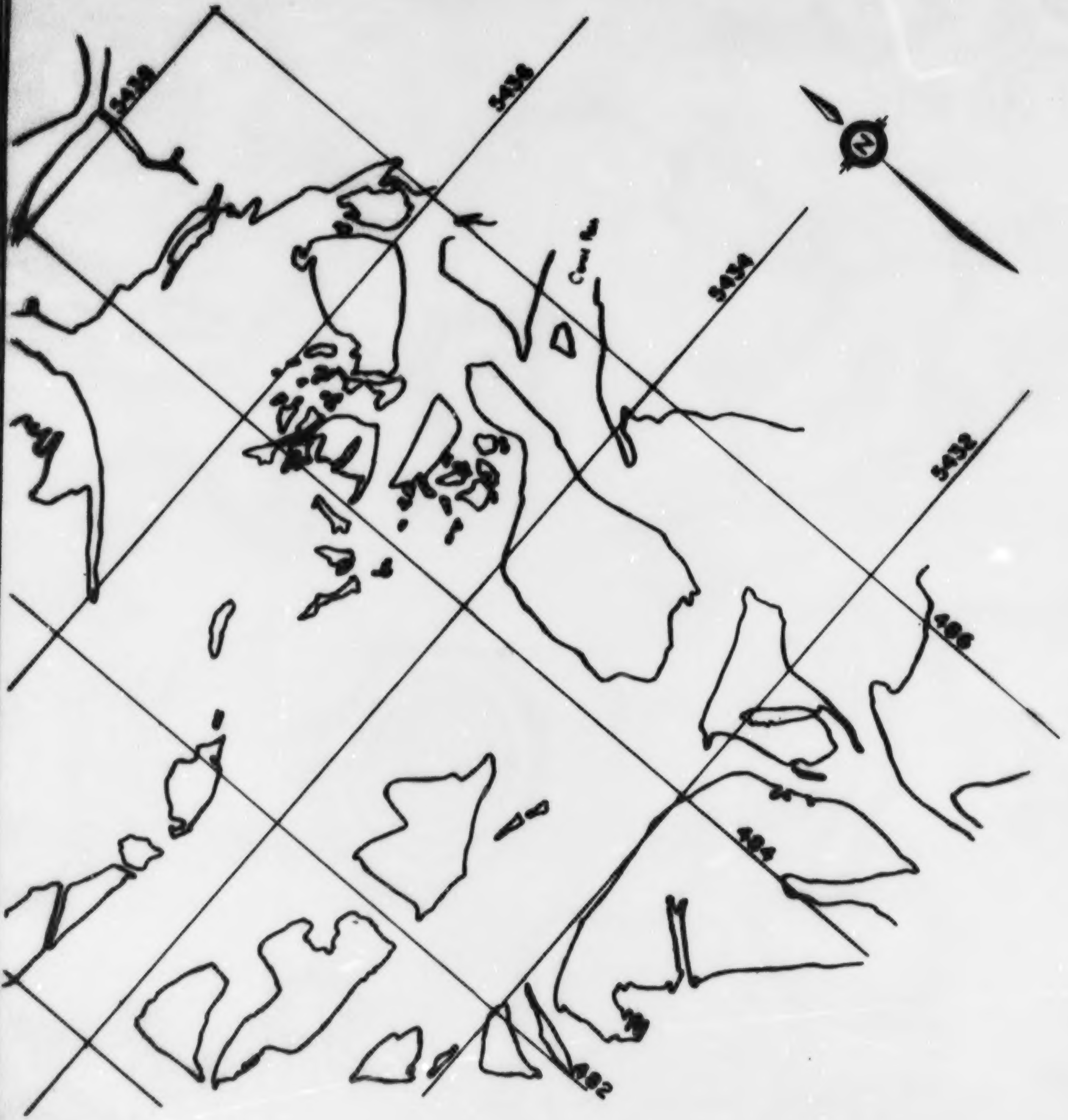
PLATE 2-16

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

CANOE PASS CHANNEL 1978
WITH PIPELINE ROUTE AND U.T.M. GRID
TIDE - 2.5 METRES GSC

MONENCO PIPELINE CONSULTANTS LTD.

[illegible] PIPELINE CONSULTANTS LIMITED



5438
5436
5434
5432
486
484
482

PLATE 2-17

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

CANOE PASS CHANNEL 1950

TIDE - 2.3 METRES GSC

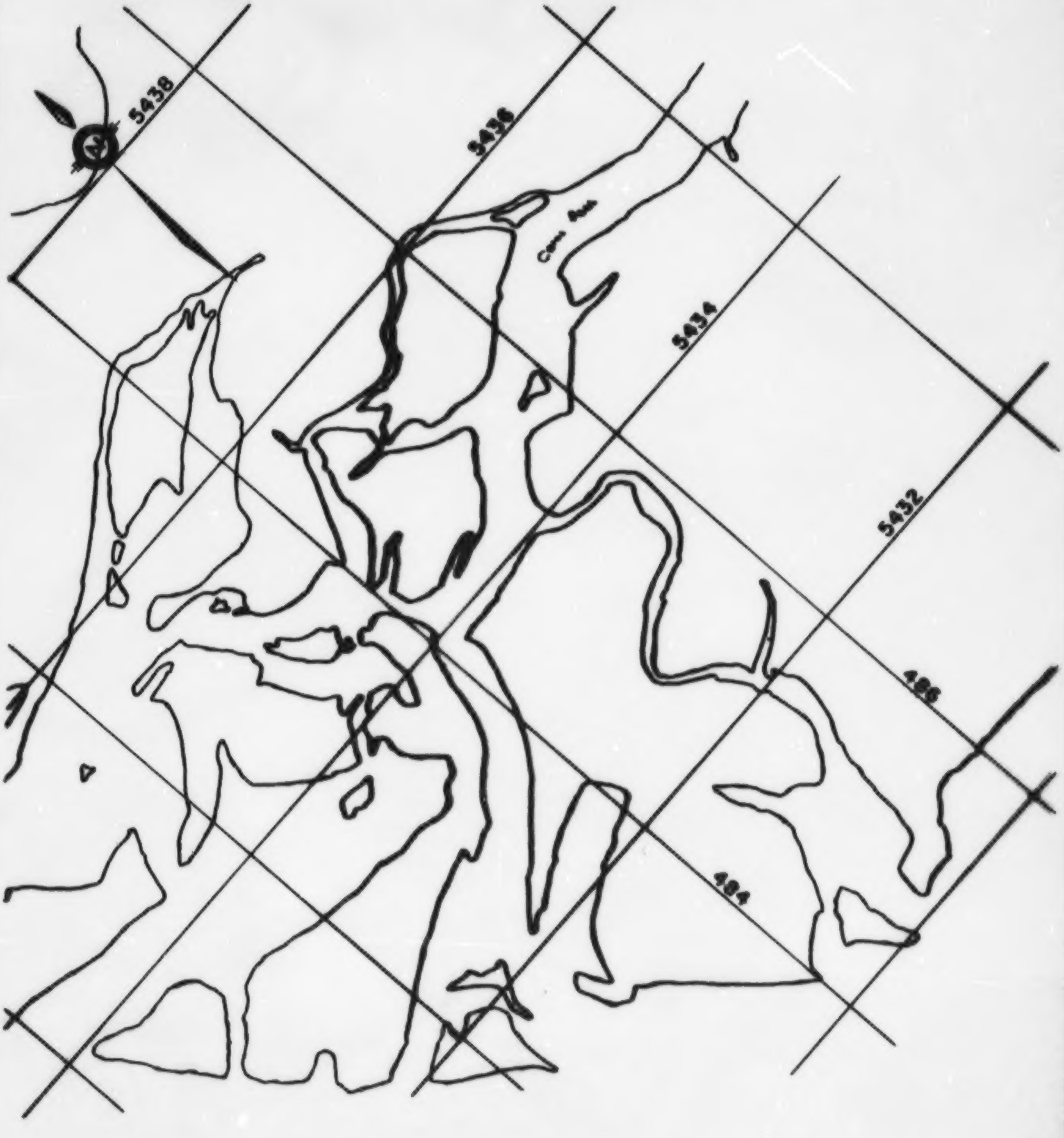
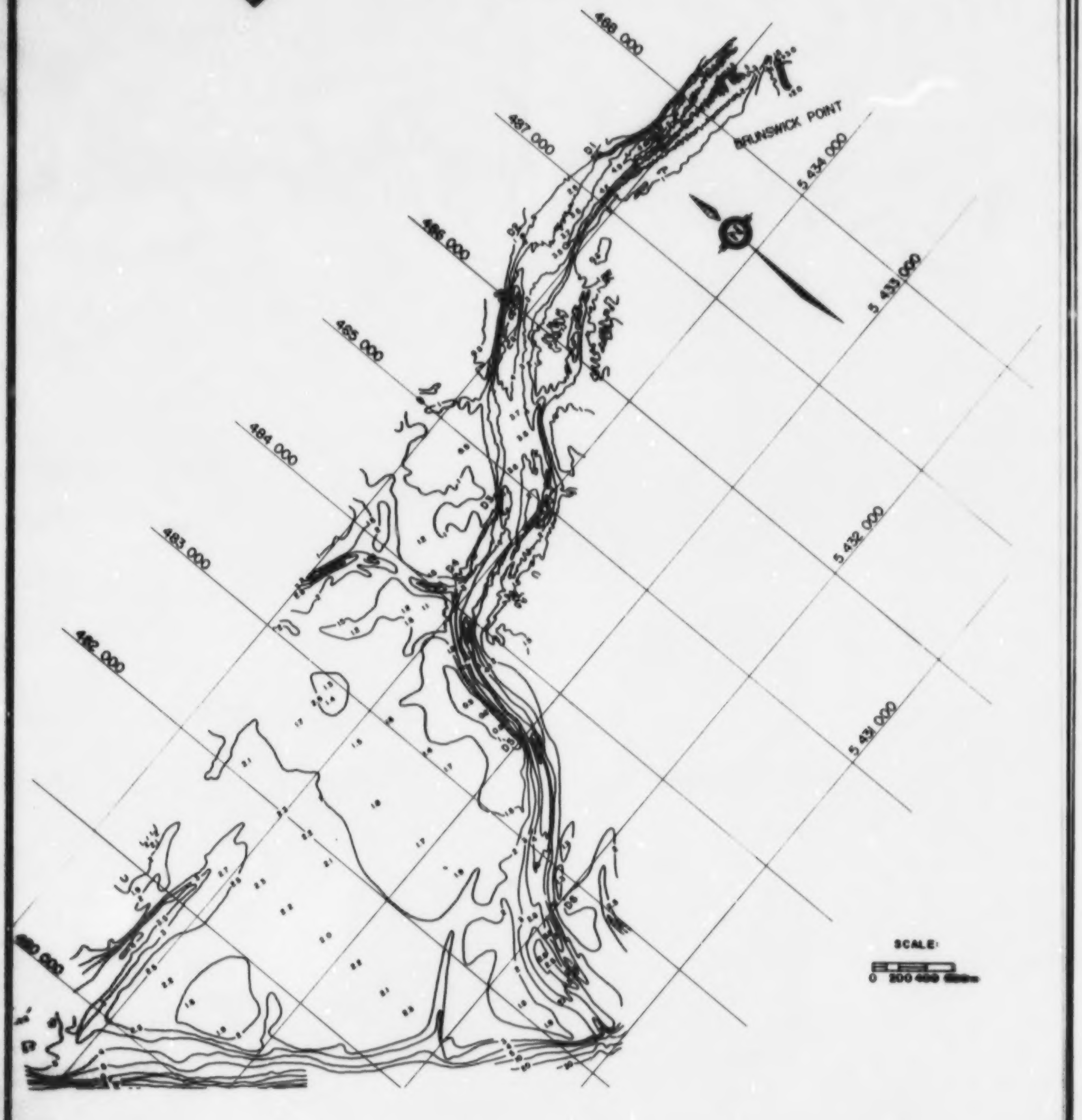

5438
5436
5434
5432
486
484
Canoe Pass

PLATE 2-18

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT
CANOE PASS CHANNEL 1978
TIDE-2.2 METRES GSC

MONENCO PIPELINE CONSULTANTS LIMITED


488 000
487 000
486 000
485 000
484 000
483 000
482 000
5 434 000
5 433 000
5 432 000
5 431 000
BRUNSWICK POINT
N
SCALE:
0 200 400 600m

NOTES:

1. SOUNDED JUNE 17 – JUNE 16 1980.
2. SOUNDINGS REDUCED TO GEODETIC DATUM.
3. ALL ELEVATIONS ARE IN METRES ARE NEGATIVE, AND ARE REFERRED TO GEODETIC DATUM.
4. NOMENCLATURE
   "D-4" DESIGNATES DOLPHIN LOCATION

PLATE 2-19

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT
CANOE PASS CHANNEL 1980
BATHYMETRIC SURVEY

PART 3

GEOLOGY

PART 3 GEOLOGY

CONTENTS

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3.1 GEOMORPHOLOGY 3-1

3.2 SURFICIAL DEPOSITS 3-3

3.3 GEOTECHNICAL PARAMETERS 3-4

3.4 SEISMICITY 3-5

3.5 LIQUEFACTION 3-6

TABLES

TABLE

3-1 Summary of Geotechnical Properties For Roberts Bank

PLATES

PLATE

3-1 Variation in Topography on Roberts Bank Foreslope

3-2 Particle Size Envelopes For Sediment Collected From the Intertidal Flats

3-3 Cross-Section Showing The Variation of Sediment Type Across The Roberts Bank Tidal Flats.

3-4 Particle Size Envelopes For Sediment Collected From The Foreslope

3-5 Geotechnical Profile of Upper Foreslope

3-6 Cross-Section Showing The Variation in Relative Density of The Sediment Across The Roberts Bank Intertidal Flats

3-7 Roberts Bank Geotechnical Program, Test Site Location Plan

3.1 GEOMORPHOLOGY

The Fraser River Delta has been formed by gradually advancing from a narrow gap in the Pleistocene uplands at New Westminster, to its present perimeter 23 km to the west. This perimeter consists of a 23 km long active delta front facing west to southwest, between Point Grey and Point Roberts, and a 13 km long inactive front that faces south onto Boundary Bay.

The Fraser River divides into a number of distributary channels across the delta. The two largest channels are the North Arm and South Arm that flow past Point Grey and Steveston respectively, and take the majority of the Fraser River's discharge. Canoe Passage is a smaller channel that flows southwest past Ladner and transports about 7% of the Fraser River's total flow.

Roberts Bank is a recently deposited part of this delta system, lying between the South Arm and Point Roberts. Its width from the shoreline to the foreslope crest varies from zero at Point Roberts to a maximum of 8.7 km at the north end of Westham Island. The Bank extends over an area of approximately 100 km^2 and slopes very gently seaward at about 0.02° from an elevation of 0.0 m at the shore to -2 m at the outer edge. This area becomes exposed during low tides and is referred to as the intertidal flats. Tidal marsh exists at the landward side of these flats adjacent to Westham Island and Brunswick Point.

At its western edge, Roberts Bank drops off quickly into the deep waters of the Straits of Georgia. This is known as the foreslope and has slopes in the order of 4° to 25° in its upper portion, depending upon location. The foreslope tends to flatten out at water depths approaching 70 m to 80 m and this break in slope is taken as the boundary between the Upper and Lower foreslope. Generally, the surface of the foreslope is smooth except at the northern parts of Roberts Bank, near the mouth of the Fraser River South Arm where a series of gullies, may be traced down the delta front. It is known that slope instability may occur on the foreslope near the South Arm because of the steep slopes and rapid rates of sedimentation in this area.

A smooth and featureless portion of the foreslope was selected for the route, where the pipeline has to cross the western edge of the delta into the Strait of Georgia (Plate 3-1). This route is well away from the more active parts of the delta front (near the mouths of the South Arm and Canoe Passage). The route selected has a maximum slope of only 4°.

3.2 SURFICIAL DEPOSITS

The deposits on the tidal flats in the vicinity of the proposed pipeline route consist mainly of dark grey to black micaceous fine sands. Locally however, lenses or channels of silty sand or sandy silt exist. Where the bank is exposed during low tides, the sediment is brown-grey in colour, probably the result of oxidation. Soil samples taken from the intertidal flats during a geotechnical investigation in 1980, were usually homogenous and rarely showed any form of fine layering or lamination. These samples occasionally contained shell fragments and plant debris. At the landward edge of the tidal flats is an area of intertidal marsh. The sediment here is composed mostly of dark silts which contain roots and plant remains. Much of the area is formed of vegetated hummocks of sediment that are dissected by small drainage channels.

The deposits on the upper foreslope of Roberts Bank are generally finer in composition than those found on the intertidal flats (Plate 3-5). They are dark grey to black in colour and generally have a laminated or finely layered fabric of fine sand and silt. Samples occasionally contained shells, shell fragments and plant debris. A series of boreholes which were drilled in the upper foreslope in 1980, suggest that these deposits do not change significantly either vertically or laterally within the slope, in the vicinity of the foreslope crest.

3.3 GEOTECHNICAL PARAMETERS

Table 3-1 summarizes the geotechnical soils data that has been collected for the tidal and upper foreslope areas of Roberts Bank. It illustrates both the variability of the soil properties within these sediments and the difference between the two areas.

Plate 3-2 (a, b and c) summarizes the results of particle size analysis carried out on soil samples collected from the intertidal flats. To show how the deposits vary within the Bank the particle size curves were grouped into three envelopes: soils containing less than 10% fines (material passing a 200# sieve), soils with between 10% and 25% fines, and soils with greater than 25% fines. The distribution of each of these groups is illustrated as a cross-section in Plate 3-3. The majority of the sediment can be classified either as fine sand or silty sand.

The deposits on the foreslope are generally finer than those found on the intertidal flats and this accounts for many of the differences in geotechnical parameters between the two regions. Plate 3-4 are envelopes of particle size distributions for soils collected from the upper foreslope. The majority of this sediment can be classified as a sandy silt. Plate 3-5 is a borehole profile showing the variability of geotechnical properties within the upper foreslope.

Plate 3-6 shows the results of penetration tests that were carried out in boreholes taken along the proposed pipeline route. These field tests involved counting the number of blows required to hammer a metal rod 0.3 metres into the ground. The resulting blow count gives an indication of the compaction or relative density of the soil, and this is directly related to the strength of the soil. The variations in relative density of the sediment on the intertidal flats is shown diagrammatically in the isometric sketch on this plate.

Static cone penetrometer soundings taken on the upper foreslope indicate that these deposits have a relative density ranging from very loose to loose. An example of one of these soundings is in Plate 3-5.

3.4 SEISMICITY

The west coast of the North American continent is known to be a seismically active area. Large earthquakes with magnitudes greater than six on the Richter Scale, have been recorded in Puget Sound, Washington State and on Vancouver Island. The largest of these had a magnitude of 7.3 and occurred in 1946 on Vancouver Island.

3.5 LIQUEFACTION

When a loose, saturated sandy soil is subjected to cyclic loading (shaking during an earthquake) the soil structure tries to compact and decrease in volume. If the water filling the soil voids cannot drain quickly enough, pore water pressures increase with each loading, and may reach a level where they equal the overburden pressure (weight of overlying deposits). If this occurs, the soil rapidly loses strength and is said to be liquefied. The liquefaction potential of the soils on Roberts Bank, was investigated(5) by testing a number of soil samples under controlled conditions simulating earthquake shaking. The results indicate that some areas of the Bank could start to liquefy in an earthquake event having a probability of occurrence of once in 160 to 330 years. Soil liquifaction could affect the pipeline in two ways:

(i) Pipeline Flotation

When a sediment liquefies it takes on the character of a dense fluid. A pipeline buried in such material could float or sink depending on whether it is less or more dense than the fluid. To prevent the pipeline from floating or sinking in the event of liquefaction on the Bank, a concrete weight coating would be used to make the pipeline neutrally buoyant in liquefied soil.

During backfilling, the sediment in the trench would be very loose, but would rapidly compact and is expected to reach a density similar to the surrounding undisturbed delta sediments. Consequently, the pipeline has been designed to have a mass specific gravity of 1.97.

It is not envisioned that the entire bank would liquefy simultaneously, so it is considered unlikely that any vertical displacement of the pipeline would occur because the unliquefied sections would anchor the pipelines if the specific gravity of the pipe were slightly different to the local soil specific gravity.

(ii) Slope Stability

Loss of shear strength due to liquefaction could cause instability of the Roberts Bank foreslope. It is thought that major soil slumping in this area could endanger the pipeline. The factors that affect slope stability can best be explained by using the analogy of a brick resting on a table that is hinged at one end. If the table top is tilted slightly the brick would not slide because of the friction produced by the roughness between the brick and the table. However, if either the inclination of the table top increased or the roughness characteristic of the contact decreased sufficiently, the brick would slide down the table. The inclination of the table represents the angle of the foreslope while the friction between the brick and the table represents the shear strength of the soil.

It follows from this analogy that the stablest part of the delta front with respect to slope stability is where the foreslope has the smallest inclination. As discussed in Section 3-1, a portion of the Roberts Bank Foreslope exists where the maximum slope is only 4° and this has therefore been selected as the most suitable route for the pipeline. Slope instability on such a gentle slope as this could only occur if the soil were to lose its shearing resistance through liquefaction.

Soil samples taken from the foreslope were tested in the laboratory under conditions which simulated earthquake shaking. The results of this soil testing programme showed that it would take a seismic event having a return period of between 160 and 330 years to liquefy the foreslope deposits.

The test results also indicated that even if these soils did liquefy they would probably retain sufficient shear strength to prevent an uncontrolled soil flow occurring on this 4° slope. Although it is difficult to quantify this residual strength, examples of liquefied slopes in Alaska (6), Japan (7), and Guatamala (8) all show that substantial residual resistance may be inherent in such liquefied materials. These examples support the case that slope instability is unlikely even if liquefaction was to occur.

In the event that soil movement did occur, then the forces acting on the pipeline would be greatest if the direction of flow was perpendicular to the pipeline, and would be smallest if the flow was parallel to the pipeline. For this reason, the pipeline is routed straight down the fall-line of the foreslope.

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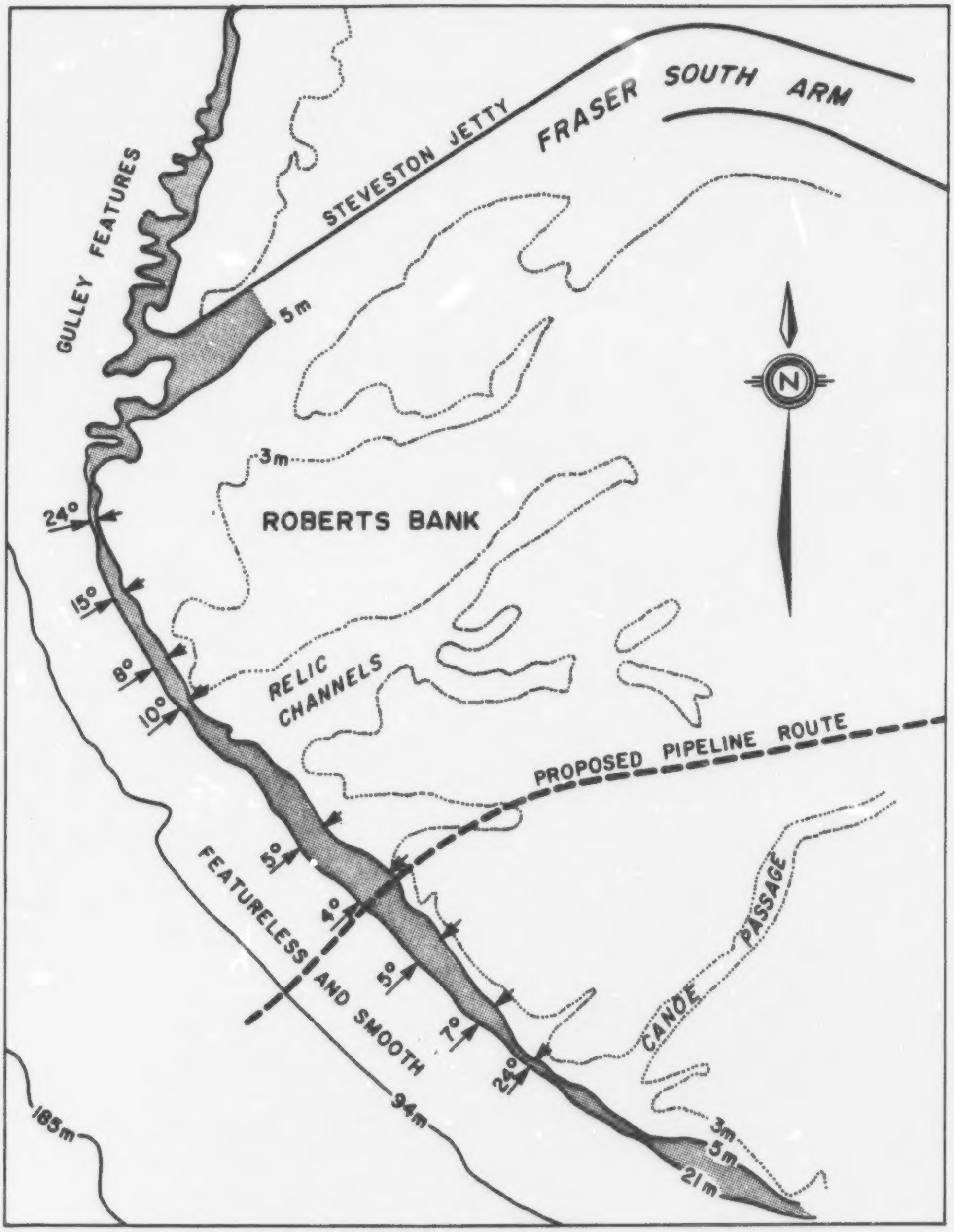
		BULK DENSITY Mg/m^3	DRY DENSITY Mg/m^3	VOID RATIO (e)	SPECIFIC GRAVITY (SG)	LIQUID LIMIT (LL)	PLASTIC LIMIT (PL)	MOISTURE %	CLAY %	SILT %	SAND %	FRICTION ANGLE Ø	COHESION (C') kPa	SULPHATE %	ORGANIC %	COEFFICIENT OF CONSOLIDATION (Cv) m^2/yr.	COEFFICIENT OF COMPRESSIBILITY (Mv) m^2/MN	COMPRENSIBILITY INDEX (Cc)	PERMEABILITY (k) CM/sec.
INTERTIDAL FLATS	MAX.	1.93	1.68	1.02	2.76	NON – PLASTIC		24.0	9	86	100	40.0	0	0.03	2.7	–	–	–	1.4×10^{-3}
	MIN.	1.59	1.36	0.64	2.73			4.9	0	0	14	34.5	0	0.00	0.3	–	–	–	1.3×10^{-5}
	AVE.	1.73	1.51	0.83	2.75			14.7	–	19	81	37.5	0	0.01	1.4	–	0.009	0.218	5.3×10^{-4}
	NO. OF SAMPLES	10	10	10	4			10	73	73	73	5	5	4	3	–	1	1	3
UPPER FORESLOPE (LESS THAN 20 METRES WATER DEPTH)	MAX.	1.85	1.35	1.26	2.79	33	28	46.6	11	84	64	32.9	11	0.05	0.5	239	0.073	0.28	4.82×10^{-6}
	MIN.	1.73	1.23	0.99	2.75	27	21	32.4	3	35	8	28.5	5	0.0	0.0	40	0.018	0.18	9.08×10^{-7}
	AVE.	1.79	1.30	1.12	2.77	31	25	36.8	8	60	32	30.7	9	0.03	0.3	160	0.040	0.23	2.93×10^{-6}
	NO. OF SAMPLES	13	13	13	12	3	3	13	29	29	29	5	5	4	4	3	3	3	4
UPPER FORESLOPE (DROP CORE PISTON SAMPLES BETWEEN 19 AND 100 METRES WATER DEPTH)	MAX.	2.08	1.60	–	–	–	–	47.5	23	75	92	41.5	0	–	4.6	–	–	0.2	5.3×10^{-3}
	MIN.	1.22	0.88	–	–	–	–	28.8	0	8	17	39.0	0	–	1.5	–	–	0.05	7.57×10^{-5}
	AVE.	1.75	1.29	–	–	–	–	33.5	8	36	56	40.3	0	–	2.9	–	–	0.13	2.69×10^{-3}
	NO. OF SAMPLES	15	15	–	–	–	–	15	15	15	2	2	2	–	8	–	–	2	2

TABLE 3-1

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

SUMMARY OF GEOTECHNICAL PROPERTIES FOR ROBERTS BANK

MONENCO PIPELINE CONSULTANTS LTD.


GULLEY FEATURES
STEVESTON JETTY
FRASER SOUTH ARM
5m
3m
ROBERTS BANK
N
24°
15°
8°
10°
RELIC CHANNELS
PROPOSED PIPELINE ROUTE
5°
4°
5°
7°
24°
FEATURELESS AND SMOOTH
CANOE PASSAGE
3m
5m
21m
94m
185m

KEY

▨ 10° ANGLE OF FORESLOPE

SCALE

0 1 2km

PLATE 3-1

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

VARIATION IN TOPOGRAPHY ON ROBERTS BANK FORESLOPE

MONENCO PIPELINE CONSULTANTS LTD.

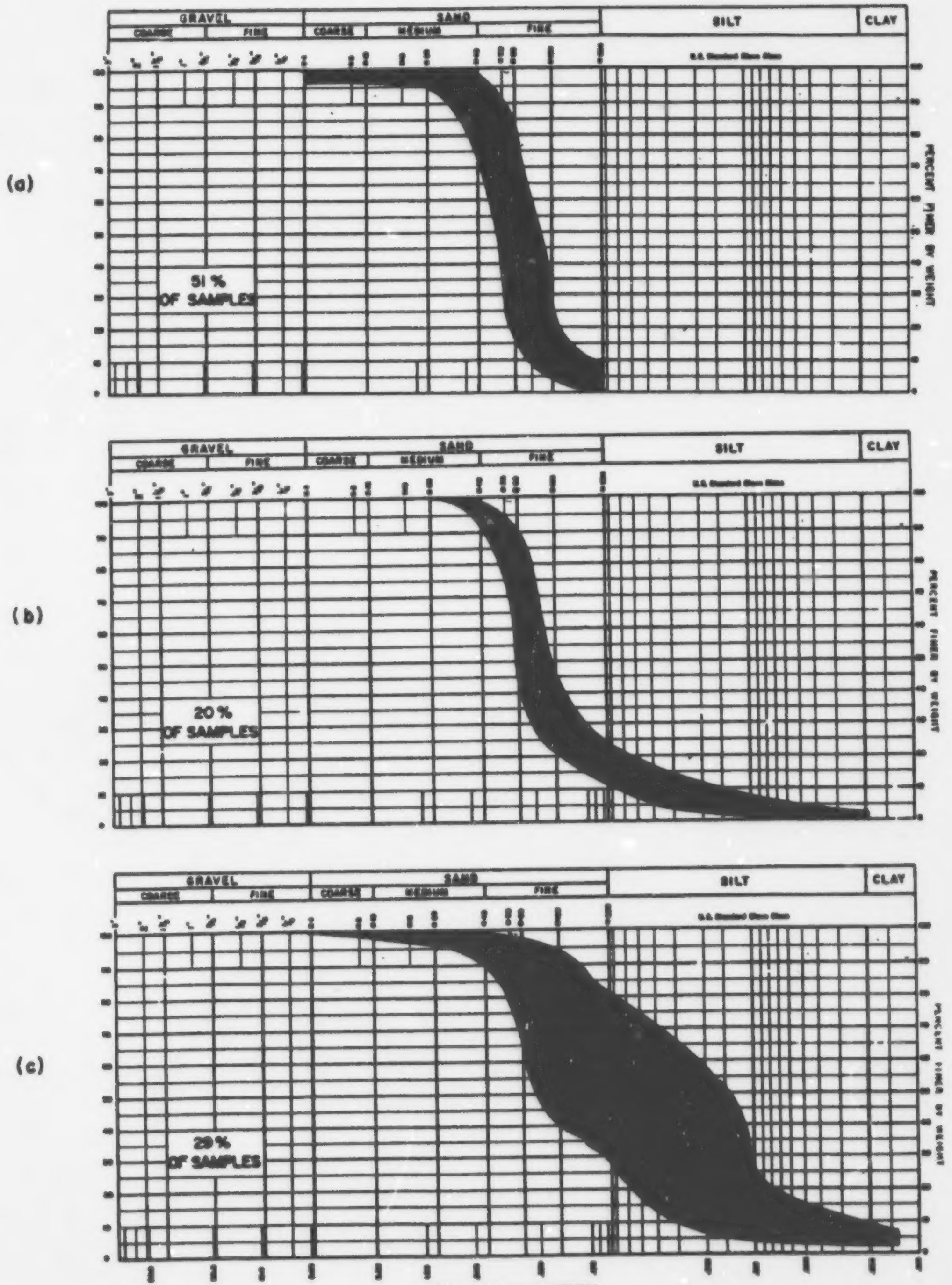
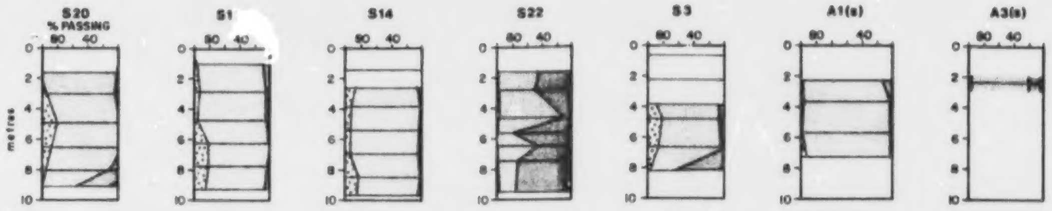


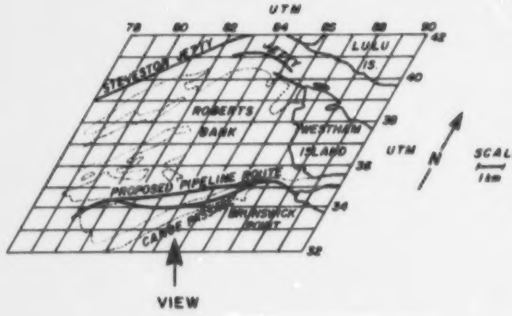
PLATE 3-2

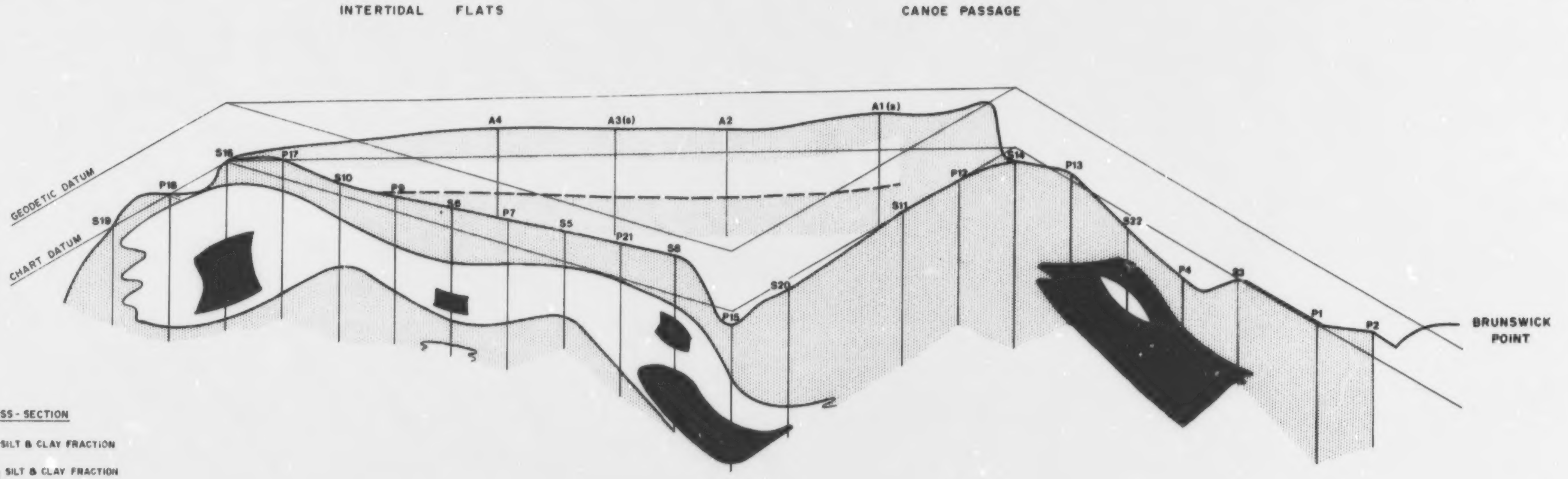
B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

PARTICLE SIZE ENVELOPES FOR SEDIMENT COLLECTED FROM THE INTERTIDAL FLATS

(a) CONTAINING <10% FINES
(b) CONTAINING 10%-25% FINES
(c) CONTAINING >25 %




UTM
78
80
82
84
86
88
90
42
40
38
36
34
32
STEVESTON JETTY
JETTY
LULU IS.
ROBERTS BANK
WESTHAM ISLAND
PROPOSED PIPELINE ROUTE
CANOE PASSAGE
BRUNSWICK POINT
UTM
N
SCALE
1km
VIEW


INTERTIDAL FLATS
CANOE PASSAGE
GEODETIC DATUM
CHART DATUM
A4
A3(s)
A2
A1(s)
S16
P17
S10
P9
S6
P7
S5
P21
S8
P15
S20
S11
P12
S14
P13
S22
P4
S3
P1
P2
S19
P18
BRUNSWICK POINT

KEY TO CROSS-SECTION

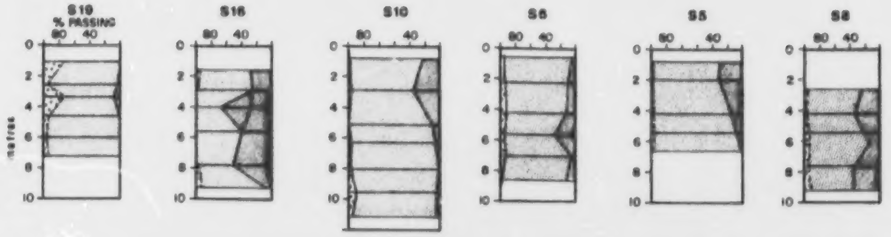
- ▒ SAND WITH <10% SILT & CLAY FRACTION
- ☐ SAND WITH >10% SILT & CLAY FRACTION <25%
- ■ SAND WITH >25% SILT & CLAY FRACTION

NOTE. REFER TO PLATE 2-5 FOR BOREHOLE LOCATIONS

ISOMETRIC SKETCH

KEY TO BOREHOLE LOGS

- ⁙ MEDIUM SAND
- ☐ FINE SAND
- ▒ SILT
- ■ CLAY



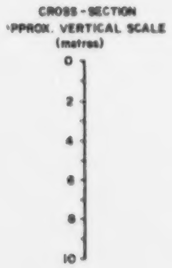

CROSS-SECTION
APPROX. VERTICAL SCALE
(metres)
0
2
4
6
8
10

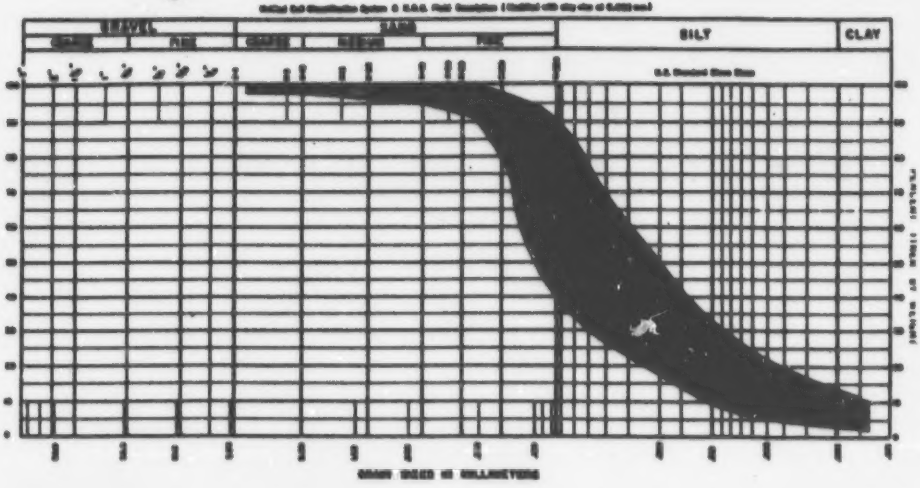
PLATE 3-3

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

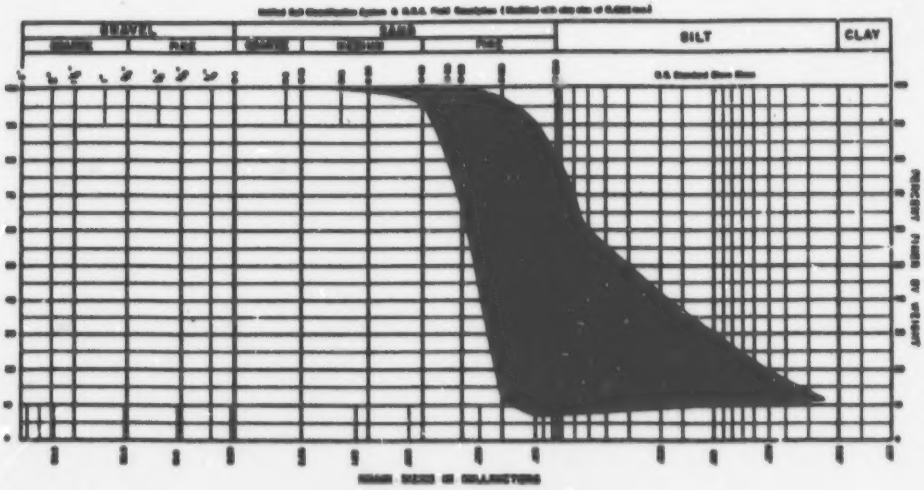
CROSS-SECTION SHOWING THE VARIATION OF SEDIMENT TYPE ACROSS THE ROBERTS BANK INTERTIDAL FLATS

MONENCO PIPELINE CONSULTANTS LTD.

(a)



(b)



(a) SAMPLES COLLECTED DURING 1980 DRILLING PROGRAM

(b) SAMPLES COLLECTED WITH PISTON CORER

PLATE 3-4

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

PARTICLE SIZE ENVELOPES FOR SEDIMENT COLLECTED FROM THE FORESLOPE

MONENCO PIPELINE CONSULTANTS LTD.

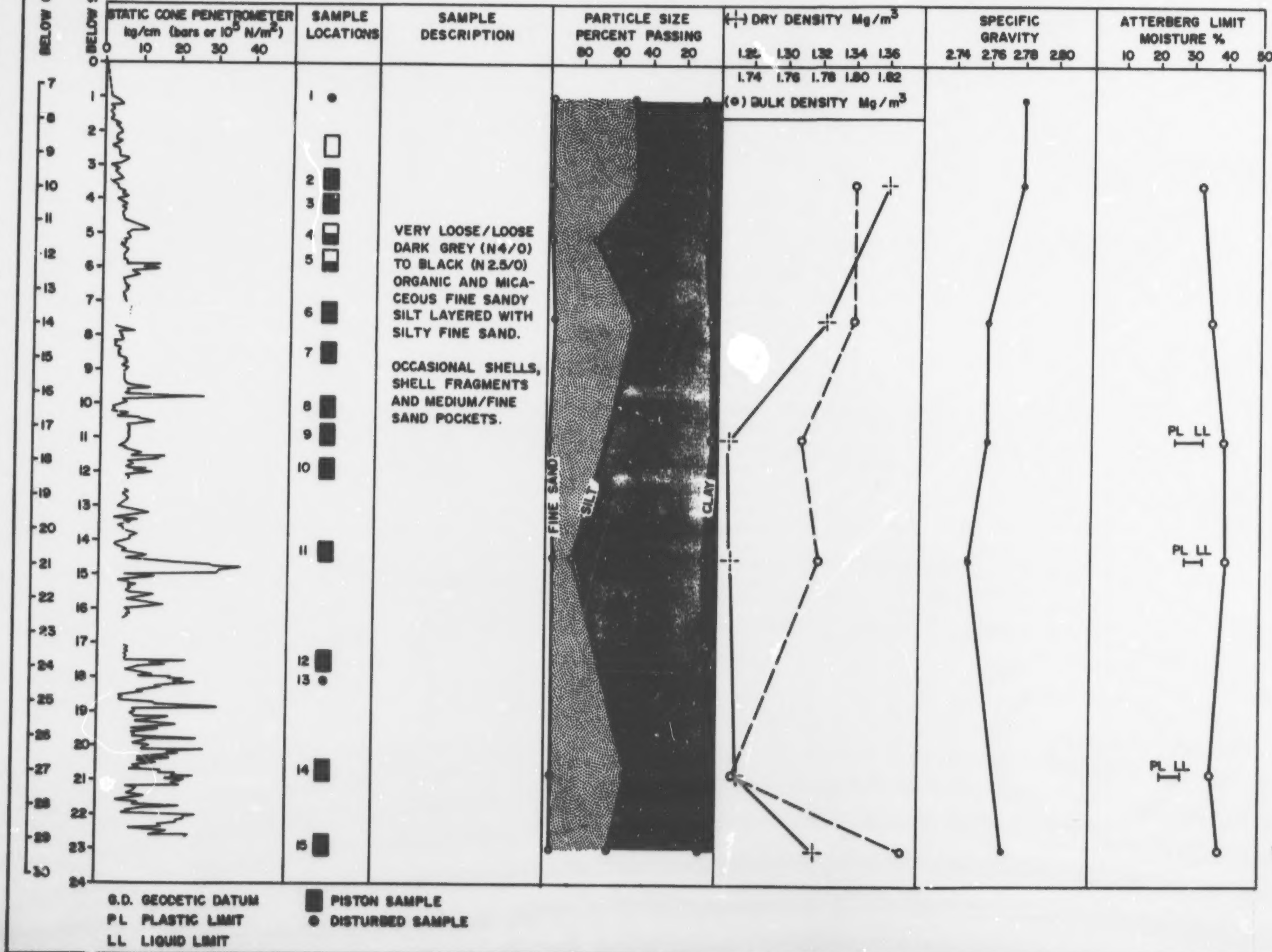
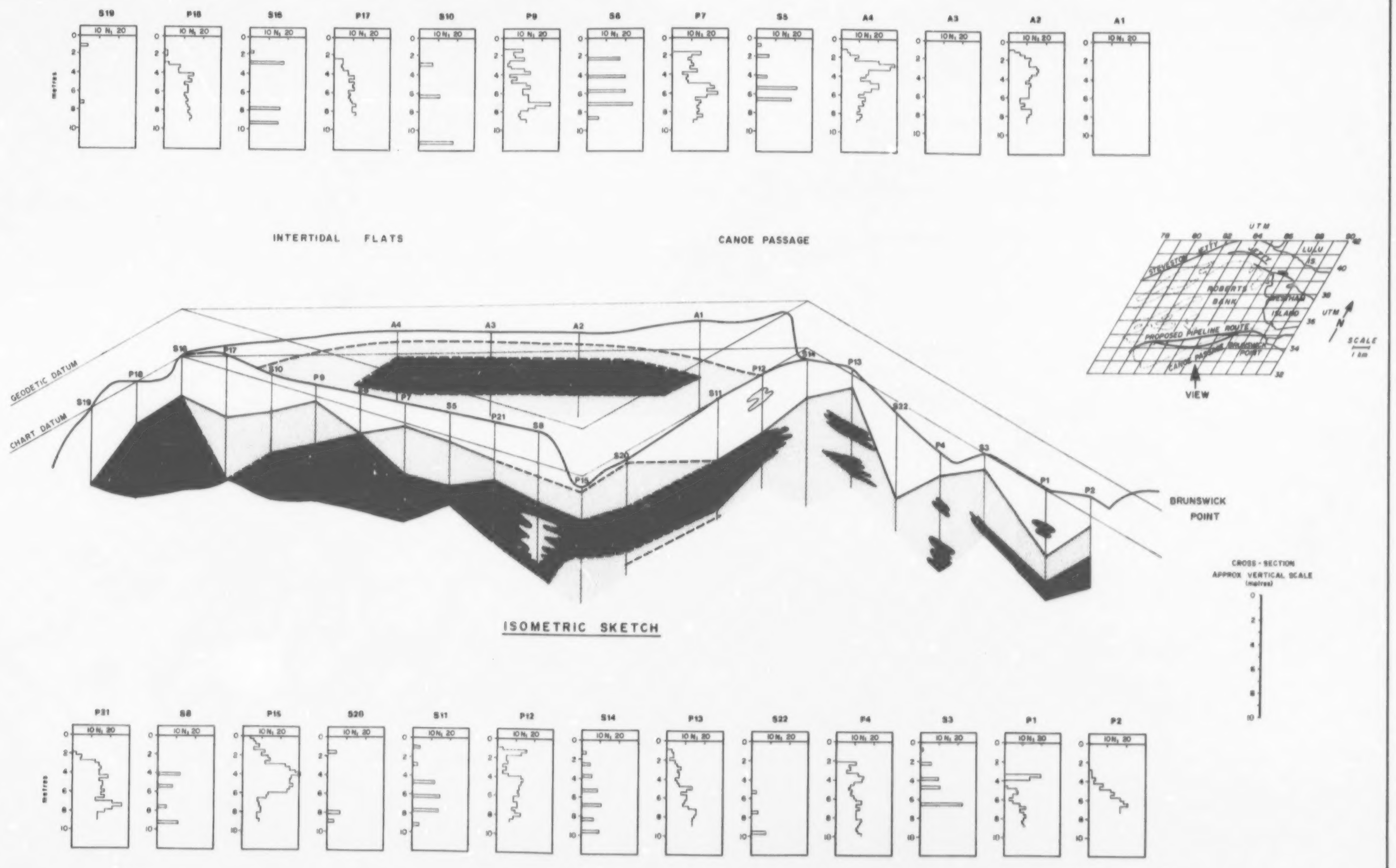


PLATE 3-5

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

GEOTECHNICAL PROFILE OF UPPER FORESLOPE


S19
P18
S16
P17
S10
P9
S6
P7
S5
A4
A3
A2
A1
10 N₁ 20
metres
0
2
4
6
8
10
INTERTIDAL FLATS
CANOE PASSAGE
GEODETIC DATUM
CHART DATUM
S21
S11
P12
S14
P13
S22
P4
S3
P1
P2
S20
P15
S8
BRUNSWICK POINT
ISOMETRIC SKETCH
P21
S8
P15
S20
S11
P12
S14
P13
S22
P4
S3
P1
P2
UTM
78
80
82
84
86
88
90
42
40
38
36
34
32
STEVESTON JETTY
JETTY
LULU IS
ROBERTS BANK
WESTHAM ISLAND
PROPOSED PIPELINE ROUTE
CANOE PASSAGE
BRUNSWICK POINT
UTM N
SCALE
1 km
VIEW
CROSS-SECTION
APPROX VERTICAL SCALE
(metres)
0
2
4
6
8
10

NOTES

N₁ = NUMBER OF BLOWS (N)/0.3m OF PENETRATION, CORRECTED TO AN EFFECTIVE OVERBURDEN PRESSURE OF 107.3 KPa (AFTER PECK, HANSON & THORBURN, 1974)

P = DYNAMIC CONE PENETROMETER HOLE (BLOW COUNT CORRECTED FOR ROD FRICTION)

S = STANDARD PENETRATION TEST HOLE

REFER TO PLATE 3-7 FOR BOREHOLE LOCATIONS

LEGEND

DENSITY RANGE (Mg/m³): 1.85 → 2.10

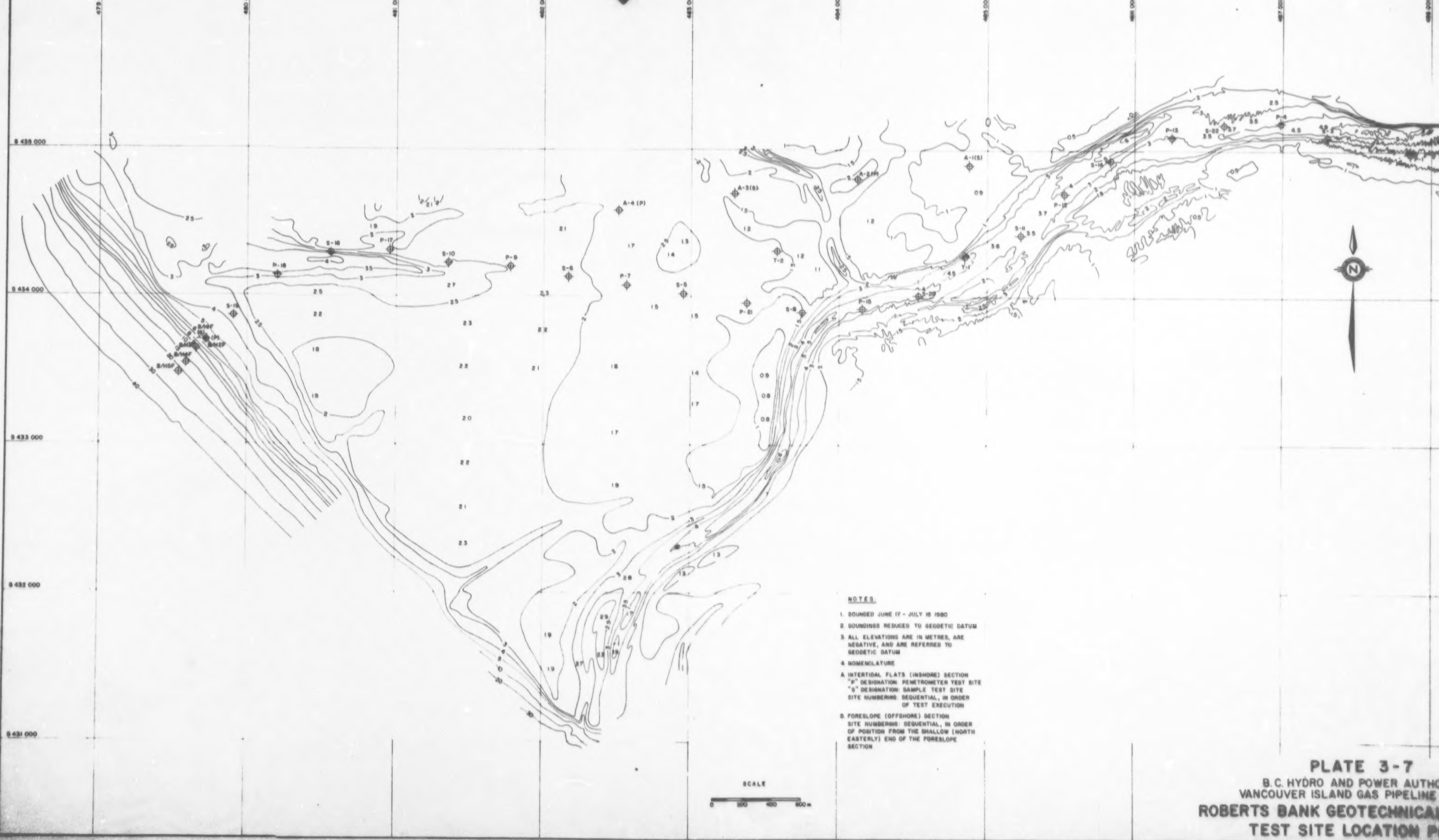
N₁ BLOWS/0.3m		RELATIVE DENSITY
0 - 4	☐	VERY LOOSE
4 - 10	▨	LOOSE
10 - 17	■	MEDIUM DENSE
> 17	■	DENSE

PLATE 3-6

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

CROSS-SECTION SHOWING THE VARIATION IN RELATIVE DENSITY OF THE SEDIMENT ACROSS THE ROBERTS BANK INTERTIDAL FLATS

MONENCO PIPELINE CONSULTANTS LTD.


479 000
480 000
481 000
482 000
483 000
484 000
485 000
486 000
487 000
488 000
5 435 000
5 434 000
5 433 000
5 432 000
5 431 000
S-16
P-17
S-10
P-9
S-6
A-4 (P)
P-7
S-5
A-3(S)
A-2(P)
T-2
P-21
S-9
P-15
A-1(S)
S-11
P-12
S-14
P-13
S-22
P-4
P-18
S-19
N
SCALE
0
200
400
600 m

NOTES

1. SOUNDED JUNE 17 - JULY 16 1980
2. SOUNDINGS REDUCED TO GEODETIC DATUM
3. ALL ELEVATIONS ARE IN METRES, ARE NEGATIVE, AND ARE REFERRED TO GEODETIC DATUM
4. NOMENCLATURE

A. INTERTIDAL FLATS (INSHORE) SECTION
"P" DESIGNATION: PENETROMETER TEST SITE
"S" DESIGNATION: SAMPLE TEST SITE
SITE NUMBERING: SEQUENTIAL, IN ORDER OF TEST EXECUTION

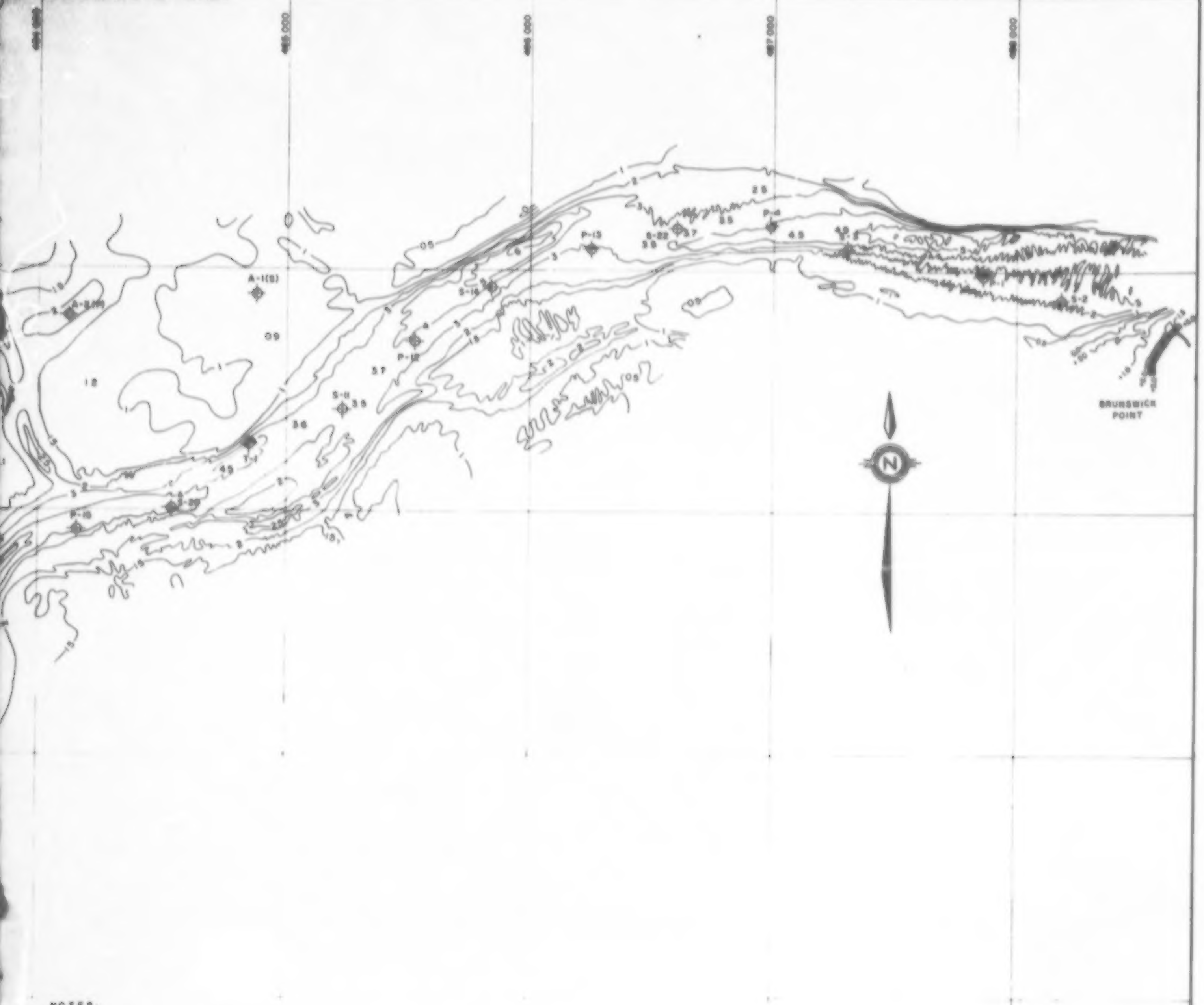
B. FORESLOPE (OFFSHORE) SECTION
SITE NUMBERING: SEQUENTIAL, IN ORDER OF POSITION FROM THE SHALLOW (NORTH EASTERLY) END OF THE FORESLOPE SECTION

PLATE 3-7

B.C. HYDRO AND POWER AUTHO
VANCOUVER ISLAND GAS PIPELINE

ROBERTS BANK GEOTECHNICA
TEST SITE LOCATION P

NSULTANTS LTD.


A-1(S)
A-2(S)
P-13
S-22
P-4
S-16
P-12
S-11
T-1
P-15
S-20
S-2
25
35
37
45
05
09
12
1
15
2
3
36
55
BRUNSWICK POINT
N

NOTES:

1. SOUNDED JUNE 17 - JULY 18 1980
2. SOUNDINGS REDUCED TO GEODETIC DATUM
3. ALL ELEVATIONS ARE IN METRES, ARE NEGATIVE, AND ARE REFERRED TO GEODETIC DATUM
4. NOMENCLATURE

A. INTERTIDAL FLATS (INSHORE) SECTION
"P" DESIGNATION: PENETROMETER TEST SITE
"S" DESIGNATION: SAMPLE TEST SITE
SITE NUMBERING: SEQUENTIAL, IN ORDER OF TEST EXECUTION

B. FORESLOPE (OFFSHORE) SECTION
SITE NUMBERING: SEQUENTIAL, IN ORDER OF POSITION FROM THE SHALLOW (NORTH EASTERLY) END OF THE FORESLOPE SECTION

PLATE 3-7

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

ROBERTS BANK GEOTECHNICAL PROGRAM
TEST SITE LOCATION PLAN

PART 4

PIPELINE DESCRIPTION, ROUTE SELECTION AND PIPELINE PROFILE

PART 4 - PIPELINE DESCRIPTION, ROUTE SELECTION AND PIPELINE PROFILE

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4.2 PIPELINE ROUTE SELECTION 4-2

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422 Shore Approach Selection 4-4

423 Route Description 4-5

4.3 BURIAL DEPTH AND PIPELINE PROFILE DESCRIPTION 4-6

PLATES

PLATE

4-1 324 mm (12 inch) Pipe, Preliminary Design

4-2 406 mm (16 inch) Pipe, Preliminary Design

4-3 Alternative Pipeline Routes - Roberts Bank

4-4 Pipeline Route and Proposed Profile - Roberts Bank

4.1 PIPELINE DESCRIPTION

411 PIPELINE DESCRIPTION

Plates 4-1 and 4-2 show cross-sections of two candidate pipe designs for a 324 mm (12 inch) and for a 406 mm (16 inch) outside diameter steel pipe. They consist of a high strength steel pipe, wrapped with a corrosion coating and a concrete outer jacket. The choice between the two will be made after a final analysis of system capacity and construction costs.

The nominated corrosion coating is coal tar enamel which is completely unaffected by seawater.

The concrete outer jacket is required to give the pipes sufficient negative buoyancy in water, for stability during construction, and also to make the pipes approximately neutrally buoyant in any areas of backfill material that may liquefy during an earthquake. The pipes would have an average specific gravity of 1.97, which is the same as the average specific gravity of the Roberts Bank soils.

Twin pipelines would be installed all the way to Vancouver Island, primarily to provide continuation of service to customers should one line be damaged by a ship's anchor or other third party activity.

4.2 PIPELINE ROUTE SELECTION

421 ROUTE SELECTION

During 1979-80 a detailed assessment of possible pipeline routes across Roberts Bank and Sturgeon Bank was undertaken.(6)(7)&(8) One important criteria was that the route must descend the foreslope in a stable area, i.e. one of shallow angle of inclination. Two areas were identified that met this criterion. The first was close to Iona Jetty, and the second due west of Brunswick Point. The first route had to be eliminated because installation of the required land pipeline through heavily developed areas was unfeasible.

For the second option, two landfall areas were evaluated. These were at Brunswick Point and on Westham Island. However, the latter alternative was eliminated primarily because of environmental considerations.

The following routes across the central region of Roberts Bank, from Brunswick Point to the most stable part of the foreslope were investigated (Plate 4-3.)

(i) Route A

From Brunswick Point, Route A follows the centre of Canoe Pass Channel to dolphin 4, when it moves out of the channel to the north and across the inter-tidal flats on a westerly heading. Eight hundred metres from the foreslope, the route swings through 60° onto a southwest heading. Length 9,850 metres.

(ii) Route B

From Brunswick Point, Route B runs down the middle of Canoe Pass Channel to between dolphins 2 and 3, when it leaves the channel to the north on a westerly heading. Six hundred metres from the foreslope the route swings through 45° onto a southwest heading. Length 9,475 metres.

(iii) Route C

Route C starts on the south side of the tidal marshes at Brunswick Point. It runs 150 metres to the north of the HVDC cables and parallel to them. After 1,500 metres, the route heads west away from the cables and crosses Canoe Pass Channel at dolphin 4.

Eight hundred metres from the foreslope, the route swings through 45° onto a southwest heading. Length 10,920 metres.

The best route was found to be Route B, which runs to the north of Canoe Pass. The route was adopted over Route A, as it was the shortest in length, takes the more direct path from Brunswick Point to the foreslope, and occupies Canoe Pass channel for less time. Route C was not adopted, as it was estimated to cost approximately 10% more than Route A or B, and had no particular benefits over them.

422 SHORE APPROACH SELECTION

The following alternative shore approaches for the selected route were investigated.

(i) Through the salt marshes at Brunswick Point.

(ii) Approximately 1.5 kilometres upstream of Brunswick Point, on the south side of Canoe Pass.

A shore approach through the salt marshes would require a 200 m long trench and would enable the dyke to be crossed at approximately 90°. It would allow the pipelines to be brought ashore earlier, thus reducing the length of the more expensive marine section.

For a landfall upstream of Brunswick Point, the pipelines would cross the dyke at a small angle which would require an unacceptably long length of the dyke to be excavated. An alternative might be to lay the pipelines in a sharp bend to the south to increase the approach angle, but this would complicate the construction due to the restricted width of the channel. Further considerations are that Canoe Pass would be blocked by the construction equipment for a considerable period of time, marine construction is more expensive than land construction, and dredging a deep trench in Canoe Pass could undermine the dykes on either side.

423 ROUTE DESCRIPTION

The route that the twin pipelines would follow is shown in Plate 4-4. The pipelines cross the dyke 3-5 m apart, at an angle of approximately 90° and pass through the tidal marsh on a northwest heading into Canoe Passage. They would run along the bed of Canoe Passage channel until midway between dolphins 2 and 3, at which point they pass through the north bank of the channel and across the intertidal flats on a westerly heading. Six hundred metres from the foreslope the pipelines would swing south through 45° onto a southwest heading.

At a point 540 m from the foreslope crest, the pipelines begin to diverge and the distance between them increases from 3-5 m to 150 m. Beyond the foreslope crest, defined as the -5 m GSC contour, they continue down the slope parallel to each other, and 150 m apart.

4.3 BURIAL DEPTH AND PIPELINE PROFILE DESCRIPTION

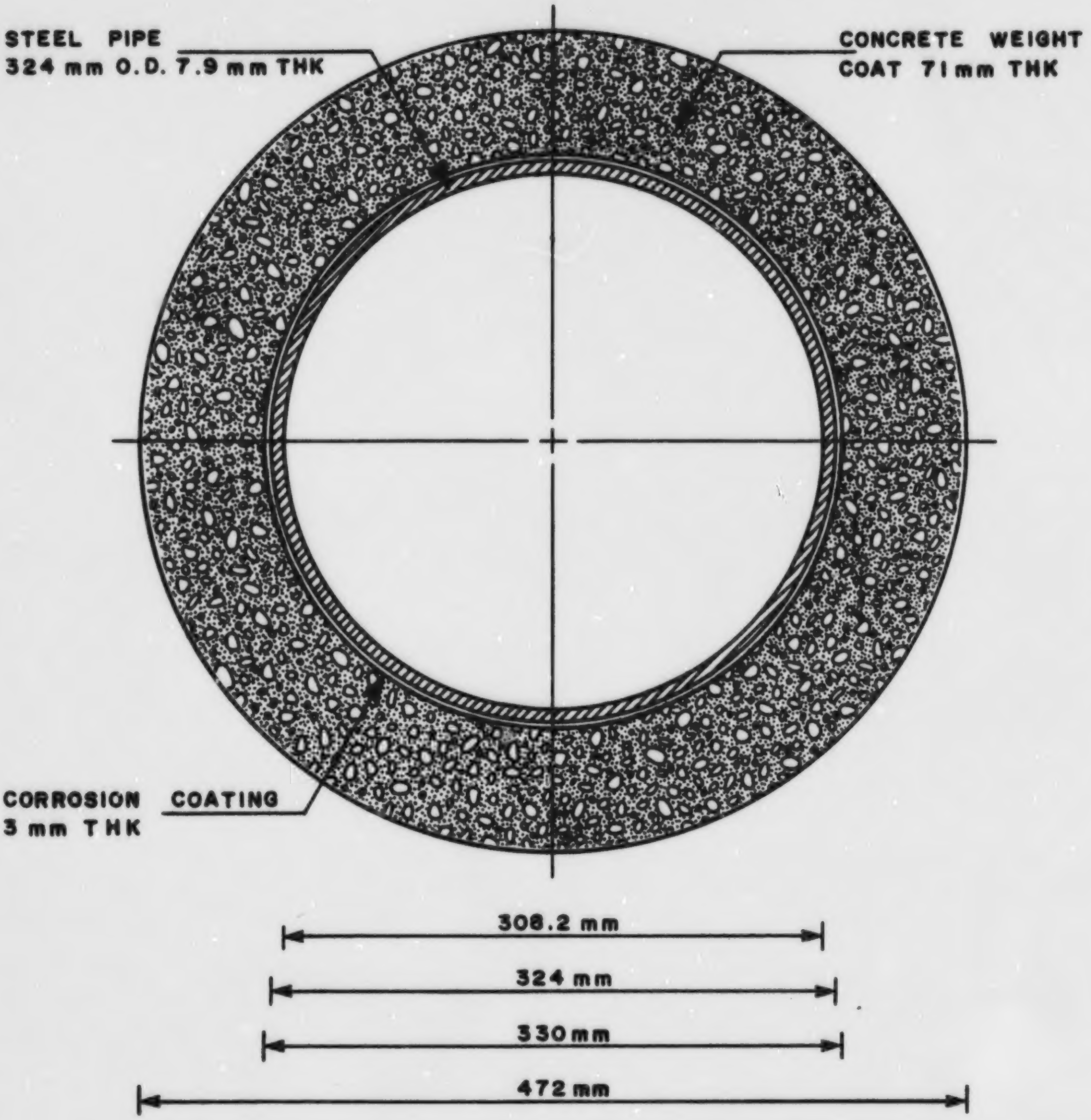
The scour potential of the Canoe Pass Channel on Roberts Bank is summarized in Section 251. It was concluded that the minimum cover to the pipeline in or close to Canoe Pass Channel should be 7.0 m below general bank level, but the burial depth could be reduced to 5.0 m for a route alignment away from the vicinity of Canoe Pass Channel, and at some distance seaward from Brunswick Point. Based on engineering judgement it was decided that for the route adopted the cover could be reduced over the outer 3,000 m of pipeline and where the distance from the pipelines to the existing channel is not less than 1,500 m.

The profile of the pipelines along the selected route is shown in Plate 4-4.

At Brunswick Point the cover to the top of the pipes would be 2 m below local marsh level, increasing to 7 m below local bank level as the pipes enter and cross the Canoe Pass channel. The trench depth would be 0.6 m deeper to allow for the diameter of the pipe. The 7.0 m cover below local bank level (7.6 m trench) would continue 1,500 m beyond the edge of the channel to Point A, where the cover would reduce to 5 m.

The 5 m cover would continue until beyond the foreslope crest at Point B. At this point fluvial scour is no longer a factor, but the 5 m cover would continue to the -13 m GSC contour to protect the pipeline on the upper foreslope from possible exposure by wave scour. From this point the cover would gradually reduce to zero by the -23 m GSC contour, Point C, and the pipelines would run down into the Strait of Georgia lying exposed on the seabed.

MONENCO PIPELINE CONSULTANTS LTD.


STEEL PIPE
324 mm O.D. 7.9 mm THK
CONCRETE WEIGHT
COAT 71 mm THK
CORROSION COATING
3 mm THK
308.2 mm
324 mm
330 mm
472 mm

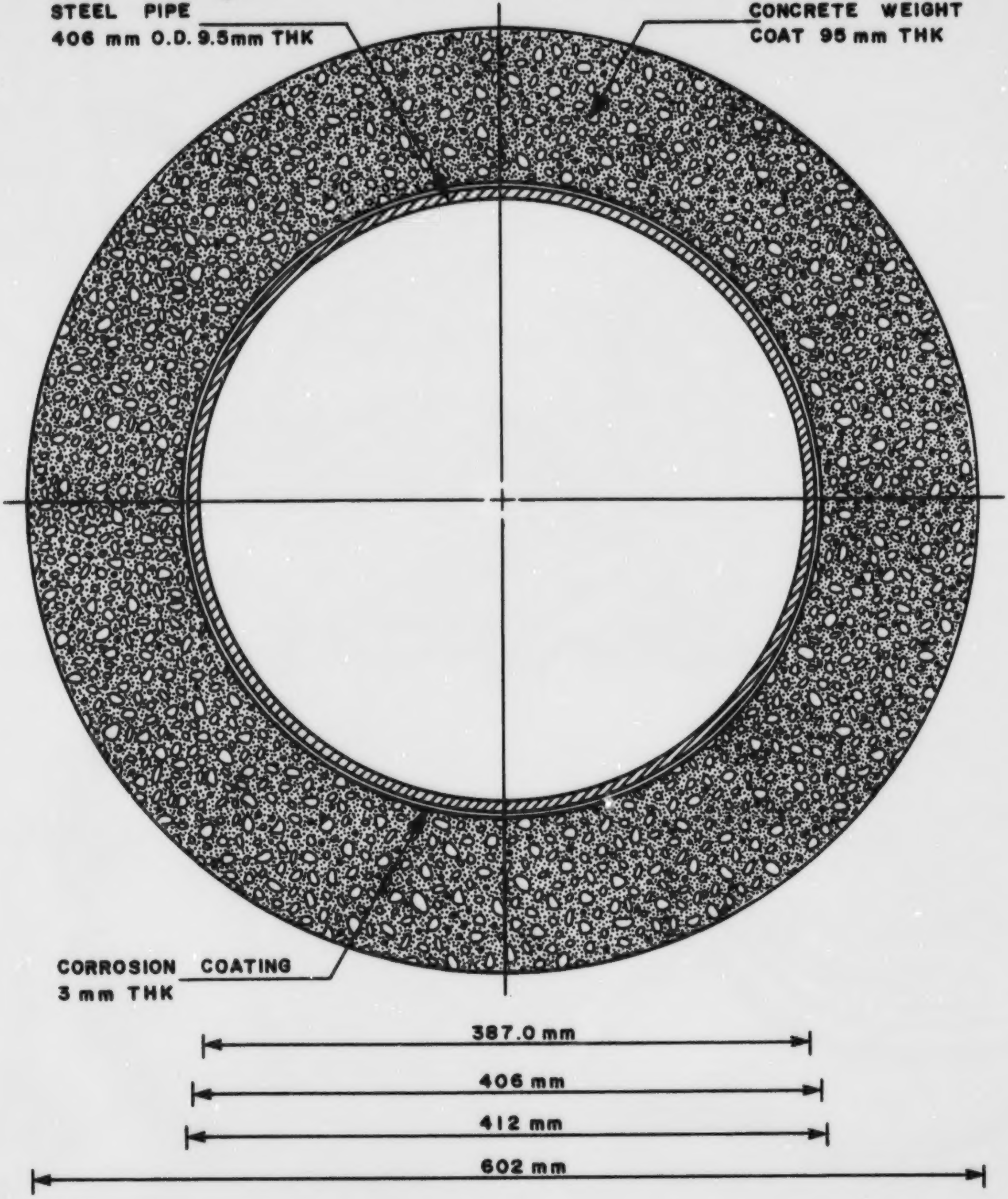
	DENSITY	WT/METRE
STEEL	7850 kg/m^3	61.68 kg/m
CORROSION COATING	1442 kg/m^3	4.70 kg/m
CONCRETE COATING	3050 kg/m^3	272.81 kg/m
		339.19 kg/m
BUOYANCY/METRE		179.17 kg/m
SUBMERGED WEIGHT		160.02 kg/m

PLATE 4-1

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

324 mm (12 inch) PIPE,
PRELIMINARY DESIGN
ROBERTS BANK

MONENCO PIPELINE CONSULTANTS LTD.


STEEL PIPE
406 mm O.D. 9.5mm THK
CONCRETE WEIGHT
COAT 95 mm THK
CORROSION COATING
3 mm THK
387.0 mm
406 mm
412 mm
602 mm

	DENSITY	WT/METRE
STEEL	7850 kg/m^3	93.79 kg/m
CORROSION COATING	1442 kg/m^3	5.89 kg/m
CONCRETE COATING	3050 kg/m^3	461.51 kg/m
		561.19 kg/m
BUOYANCY/ METRE		291.75 kg/m
SUBMERGED WEIGHT		269.44 kg/m

PLATE 4-2

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

406 mm (16 inch) PIPE,
PRELIMINARY DESIGN
ROBERTS BANK

MONENCO PIPELINE CONSULTANTS LTD.

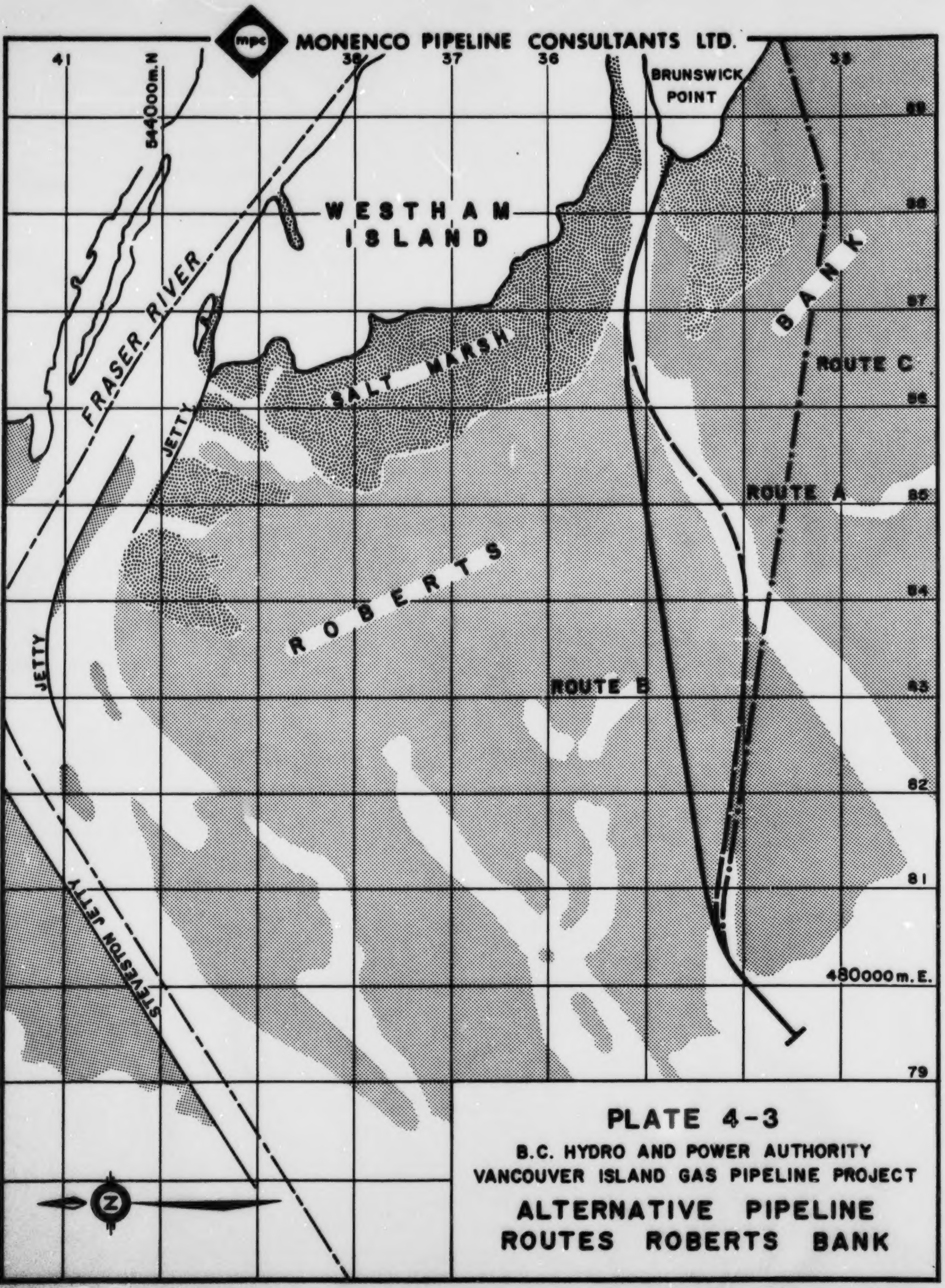
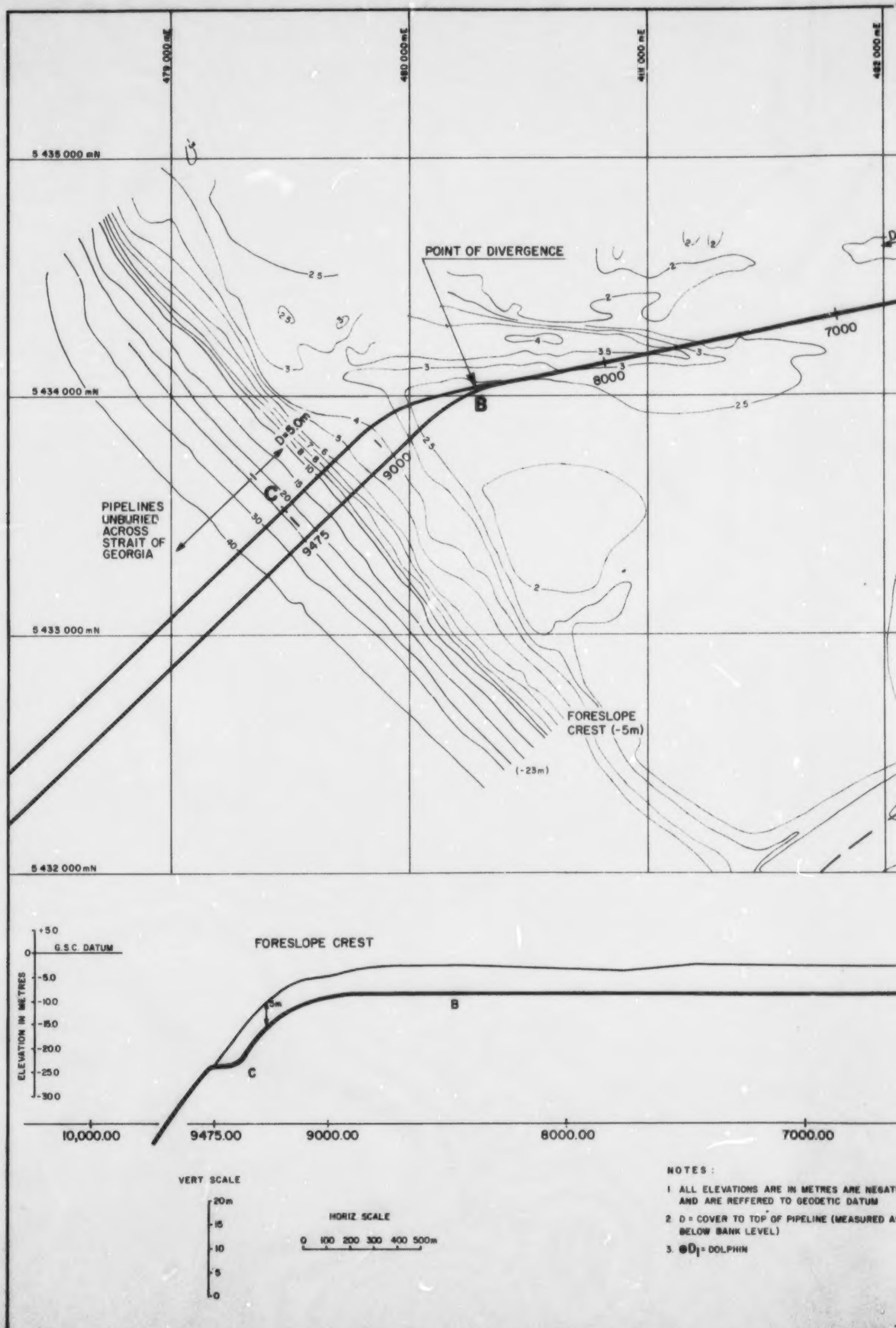

mpc
41
38
37
36
33
544000m.N
BRUNSWICK POINT
WESTHAM ISLAND
FRASER RIVER
JETTY
SALT MARSH
BANK
ROUTE C
ROUTE A
ROBERTS
ROUTE B
JETTY
STEVESTON JETTY
89
88
87
86
85
84
83
82
81
480000m.E.
79
Z

PLATE 4-3

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

ALTERNATIVE PIPELINE ROUTES ROBERTS BANK


479 000 mE
480 000 mE
481 000 mE
482 000 mE
5 435 000 mN
5 434 000 mN
5 433 000 mN
5 432 000 mN
POINT OF DIVERGENCE
B
C
D=5.0m
7000
8000
9000
9475
PIPELINES UNBURIED ACROSS STRAIT OF GEORGIA
FORESLOPE CREST (-5m)
(-25m)
2
2.5
3
3.5
4
5
6
8
10
15
20
30
40
FORESLOPE CREST
G.S.C. DATUM
ELEVATION IN METRES
+5.0
0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
5m
10,000.00
9475.00
9000.00
8000.00
7000.00
VERT SCALE
20m
15
10
5
0
HORIZ SCALE
0 100 200 300 400 500m

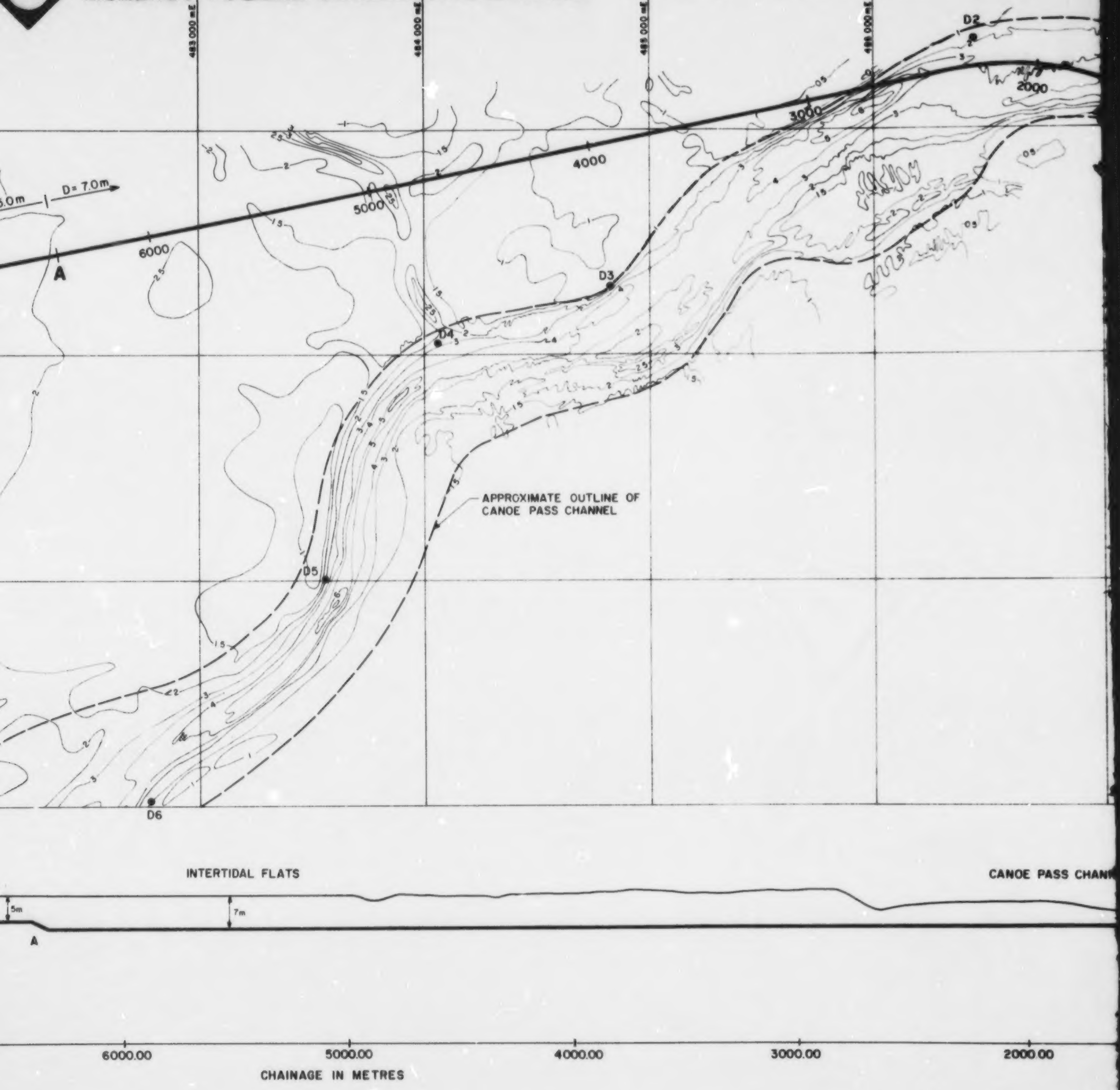
NOTES :

1 ALL ELEVATIONS ARE IN METRES ARE NEGAT
AND ARE REFFERED TO GEODETIC DATUM

2 D = COVER TO TOP OF PIPELINE (MEASURED A
BELOW BANK LEVEL)

3. ●D1 = DOLPHIN

MONENCO PIPELINE CONSULTANTS LIMITED


483 000 mE
484 000 mE
485 000 mE
486 000 mE
D2
2000
3000
4000
5000
6000
D= 7.0m
.0m
A
D3
D4
D5
D6
APPROXIMATE OUTLINE OF CANOE PASS CHANNEL
INTERTIDAL FLATS
CANOE PASS CHAN
5m
7m
A
6000.00
5000.00
4000.00
3000.00
2000.00
CHAINAGE IN METRES

ISTANCE

B.C
VANCO

PIPELINE R

TS LIMITED

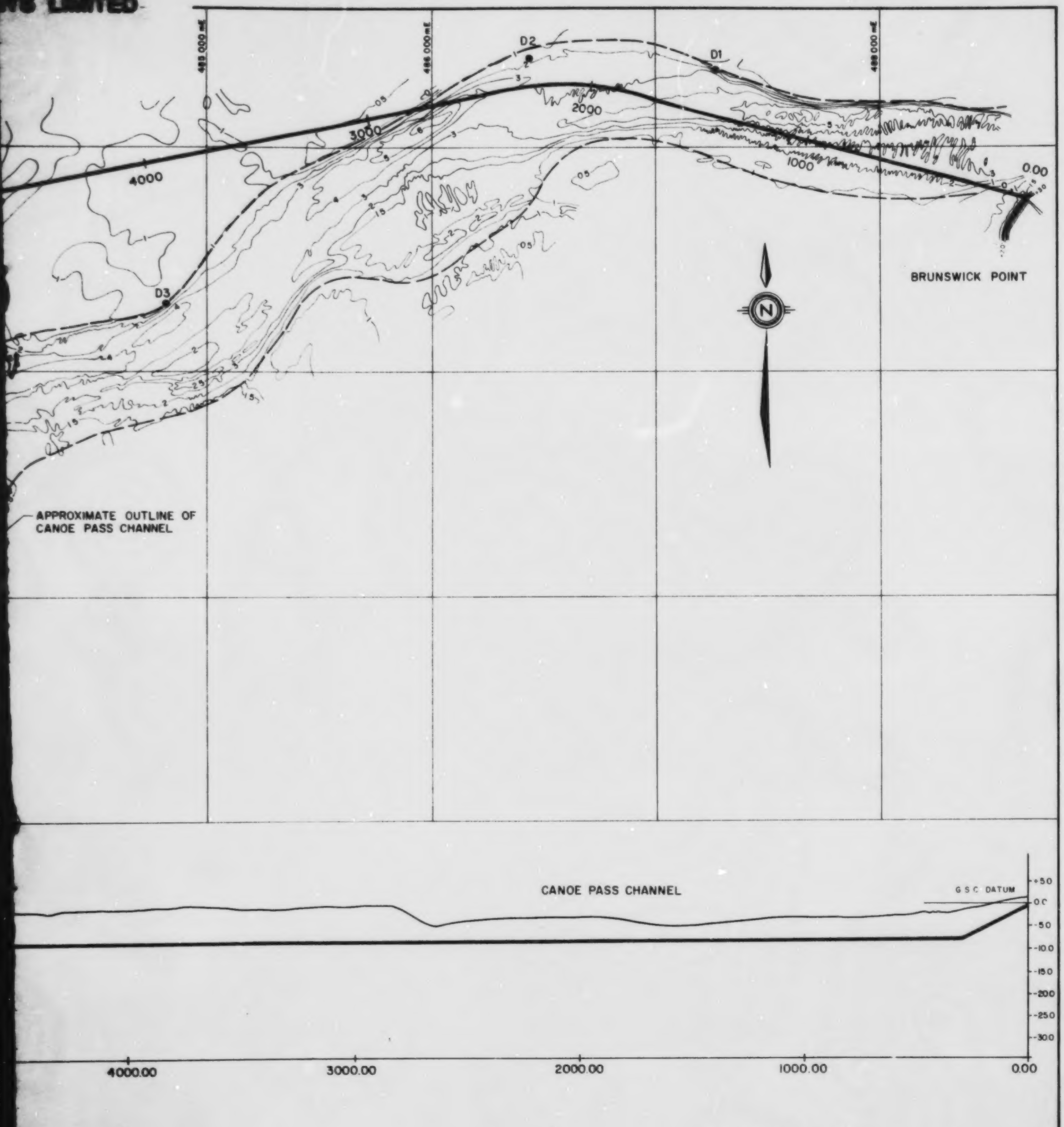

485 000 mE
486 000 mE
488 000 mE
D2
D1
D3
4000
3000
2000
1000
0.00
BRUNSWICK POINT
N
APPROXIMATE OUTLINE OF CANOE PASS CHANNEL
CANOE PASS CHANNEL
G S C DATUM
+5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
4000.00
3000.00
2000.00
1000.00
0.00

PLATE 4-4

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

PIPELINE ROUTE AND PROPOSED PROFILE ROBERTS BANK

PART 5

CONSTRUCTION METHODOLOGY

PART 5 - CONSTRUCTION METHODOLOGY

CONTENTS

PAGE

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INTRODUCTION 5-1

511 Cutter Suction Dredge 5-3

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515 Personnel Requirements 5-9

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5.1 EQUIPMENT

INTRODUCTION

In 1978 Montreal Engineering Company Ltd. performed a technical review of the various pipeline installation and burial methods(9) which might be applicable to the Roberts Bank section. The pipeline installation methods considered were bottom pull, surface pull, reelship and shallow water laybarge. The burial techniques considered were jetting, fluidization, ploughing, and dredge and backfill. The installation by surface pull was considered impracticable due to the high currents that occur over the bank. The combination of installation by bottom pull and burial by jetting, fluidization or ploughing, was investigated. The maximum burial depths achieved by these methods has not exceeded 3 - 4 m, which is not sufficient, as a cover of 7 m is required over the major portion of the route. Therefore, it was concluded that the only method available to achieve the required cover was by dredging. However, it was not considered feasible to pull the pipe into a predredged trench, due to the problems of stockpiling the dredged material and keeping the trench open long enough to complete the pull. The review concluded that the most suitable construction method was a combination of pipeline installation by shallow water laybarge, and pipeline burial by dredge and backfill. The dredge and laybarge would combine to form a construction spread which would move slowly across the banks, laying and burying the pipe. At the front of the spread, a hydraulic dredge would excavate the bank material to form a trench in which the shallow water laybarge would float simultaneously laying the twin pipelines approximately 3-5 m apart. Behind the laybarge, the discharge unit would deposit the excavated soil as backfill. For brevity, this construction method will be referred to in this report as the "bathtub" method. The method is presented schematically in Plate 5-1 and pictorially in Plate 5-2.

Due to the size of trench, the rate of trench excavation by the hydraulic dredge would be slower than the lay rate of the shallow water laybarge. Therefore, the rate of progress of the construction train across the banks would be governed by the hydraulic dredge. The dredge would work 24 hours per day, but the laybarge could keep up by working one 12 hour shift per day.

A hydraulic dredge may be operated in two ways, either as a cutter suction or an open suction dredge. The two types are described in Sections 511 and 512.

The open suction dredge is suitable for operation only in granular material which runs freely to the open suction. As the majority of the material across the banks has a silt content of 10 - 25% it is expected to be unsuitable for an open suction dredge and it is envisaged that a cutter suction dredge would be used.

511 CUTTER SUCTION DREDGE

The cutter suction dredge is a hydraulic dredge which operates by loosening material with a rotary cutter located at the bottom end of a heavy ladder, and removing the material in slurry form by lifting it up by pump, through a suction pipe, and disposing of it through a discharge pipe. The dredge is anchored to the bottom by two spud poles which are arranged so that the dredger can advance by pivoting alternately around each one. While one spud is anchored in the bottom, the other is being moved forward. The pivoting, or swinging from side to side is achieved by pulling on side wires anchored on both sides of the dredging path ahead of the dredge, as shown in Plate 5-3. The anchors are positioned either by anchor booms on the dredge or by using an anchor handling barge and a small tug. A schematic profile of a typical cutter suction dredge is presented in Plate 5-4. A high accuracy of excavation is possible with this type of dredge.

Cutter suction dredges are rated by the diameter of their discharge pipe. These range from between 150 mm and 1,200 mm, but are normally between 300 mm and 600 mm. Corresponding production rates are dependent upon various factors such as soil characteristics, digging depth and length of discharge line. Typical cutter suction dredge production rates are shown in Plate 5-5. It is envisaged that either a 600 mm (24 inch) diameter or a 660 mm (26 inch) diameter dredge would be used on this project. For the type of soil found across Roberts Bank, the maximum production rates would be 1,300 m^3 per hour and 1,500 m^3 per hour respectively. The dredge would proceed across the untertidal flats at a rate of 60-100 m per day depending upon the particular section of the crossing. The rate through Canoe Pass would be approximately 85 m per day.

The plan dimensions of a typical dredge are approximately 76 m x 14 m and would require a channel width at low water of about 30 metres to accommodate the swinging motion. Depending upon the depth and underwater side slopes of the trench, this would result in a trench bottom width of between 10 - 20 metres.

The maximum dredging depth for a 660 mm diameter cutter suction dredge is in the order or 30 - 35 metres, when an extension ladder and booster pump are fitted. These would enable the trench to be excavated to the -23 m GSC contour.

Cutter suction dredges are strongly affected by wave and current conditions. Movement of the dredge due to wave action can cause various problems including impact of the cutterhead against the bottom, loss of contact between the cutterhead and the bottom, and difficulties with the discharge line if it is floating. The use of a submerged discharge line would help reduce the latter problem and the substitution of anchor lines for the spuds can allow work to be carried out in more severe conditions. Limiting wave heights are between 1.0 m and 1.2 m, although the efficiency of the operation drops when waves exceed about one half of this height. Previous dredging experience on Roberts Bank, has shown that the sea state associated with winds approaching 9 m/s (20 mph) requires that dredging operations shut down.

Currents can also affect cutter suction dredge by creating drag on the ladder and the discharge line. However, the maximum currents of about 1 to 1.5 m/sec, which are expected to occur on this project are within the operational limits of a cutter suction dredge.

512 OPEN SUCTION DREDGE

The open suction dredge is a very similar item of equipment to the cutter suction dredge. The principal difference is that the open suction dredge replaces the rotary cutter with an open suction head, which is usually supplied with high pressure water. This water is discharged through jets located around the perimeter of the suction head, and this action loosens the bottom material before it enters the suction pipe. Since there is no mechanical cutting action, the open suction dredge is suitable for operation only in granular materials, which flow towards the open suction. This produces a V-shaped trench, the cross-section of which is smaller than that produced by the cutter suction. Typically, the rate of production is 25 - 50% greater than that of a similar sized cutter suction dredge. However, the accuracy of excavation which can be achieved is poor. The main advantage of open suction, if the material were suitable, would be the shorter construction period as a result of the smaller trench cross-section and the greater rate of production.

The open suction dredge would be equally affected by weather and current conditions as the cutter suction dredge.

513 SHALLOW WATER LAYBARGE

The basic concept of a laybarge is that of a moored platform upon which pipe is assembled and lowered down a launching ramp to the seabed in a continuous string. Some offshore pipeline contractors own and operate specially built shallow water laybarges. In most cases, however, they are purpose rigged from locally available pontoons or scows, and subsequently dismantled on completion of the project. Typically, one or more shallow draft pontoons may be joined together to form a platform upon which are mounted a crane, mooring winches, welding machines, X-ray and field joint equipment, and a pipe launching ramp. The plan dimensions for such a platform are approximately 85 m x 14 m. Plate 5-6 shows a schematic profile of a typical shallow water laybarge equipped with anchor lines. When anchors are used, these are placed ahead of the barge by an anchor handling tug. The laybarge then moves forward by winching in on the lines. Instead of anchor lines, shallow water laybarges may be equipped with spud poles, in which case a small tug is used to push the laybarge forward when the spuds are retracted.

The laybarge would have sufficient storage area to store two days supply of pipe joints (12 m lengths of pipe). These would be shipped to the laybarge by small cargo barges, as required, to stock up the laybarge. The pipe barges would be towed out at high tide and moored alongside the laybarge. As the tide recedes, the barges would sit with the laybarge in the "bathtub".

The laybarge would be less sensitive to weather conditions than the dredge and could continue operation in increasing seas. However, should wave heights approach 2.5 m then the laybarge would have to cap the pipelines and lower them into the trench. The pipelaying would not be affected by currents up to 1.5 m/s.

A buckle detector would be towed in each line as it is laid, to ensure that the pipeline had not been deformed in the laying process. A buckle detector is a pair of circular plates, held rigidly about 1 m apart, that sits inside the pipe behind the touch down point. Each time the laybarge advances the buckle detector is pulled forward the same distance. The buckle detector would jam in the pipe, if the pipe was deformed or buckled in the laying process. A taut towing wire would alert the barge crew, and the laybarge would be backed up to recover the damaged section of pipe.

514 DISCHARGE PONTOON

The function of the discharge pontoon is to backfill the trench by spreading the dredged material evenly over the trench width, with as little loss of material as possible. A schematic profile of a suitable discharge pontoon is shown in Plate 5-7.

For land reclamation projects, when loss of material is not a concern, the discharge nozzle is usually fixed in the horizontal position and the dredged material is discharged onto the water surface, resulting in high surface turbidity.

The best means of reducing losses of dredgate during the backfill operation is to use a submerged discharge nozzle. For this purpose the discharge pipe would be fitted with flexible joints to allow the nozzle to be raised or lowered and its angle relative to the water to be varied.

When possible, the nozzle would be below the adjacent bank level to reduce the influence of the tidal currents on the discharge plume. However, the nozzle would occasionally have to be raised above this level to complete the trench flush with the surrounding bank level.

A conical expansion piece, as detailed in enlargement A, (Plate 5-7), or a splash plate as detailed in enlargement B, (Plate 5-7), when fitted to the nozzle would help reduce the turbidity below the surface and the impact velocity on the trench bottom.

The pontoon would swing from side to side to ensure even backfilling by pulling on side wires anchored each side of the trench. A small work boat would be required to pick up and reposition the side anchors.

The unit would be constructed from a number of pontoons of sufficient size to support the discharge pipe, anchor winches, and derrick for the raising and lowering of the discharge pipe. It may also be feasible to adapt an existing small suction dredge for the purpose.

The unit would be subject to similar weather condition limitations as the dredge.

515 PERSONNEL REQUIREMENTS

The dredge, as the governing item in the construction train, would work a 24 hour day. There would be three shifts of approximately eight men each. The laybarge would be able to lay sufficient pipe to keep up with the dredge by working one 12 hour shift per 24 hour day. It would require a crew of approximately 40 men to operate the barge, to weld and to lay the twin pipelines. When crossing the foreslope, during the pull to shore, and during tie-ins, as described in Sections 521, and 522, the laybarge would be required to work a 24 hour day. The crew would be increased to enable two 12 hour shifts to be worked.

516 MARINE TRANSPORT REQUIREMENTS

Access is required at all times to the construction train for crew changes, for the delivery of light stores and in case of emergencies. For the majority of the time this would be by means of a shallow draught work boat. The construction train would require three or four work boats for this purpose. At very low tides when the depth of water over the bank is insufficient, a hovercraft or helicopter would have to be used.

Joints of pipe would be shipped out to the laybarge by shallow draught barges towed by tugs, at regular intervals. The barges and tugs would be able to travel over the intertidal flats at high tide, when the water depth would be between 2-3 m. It is expected that one trip per day or less would be sufficient to supply the laybarge with pipe, assuming space for a minimum of two day's storage was available on the laybarge. The barges would be brought along side the lee (sheltered) side of the laybarge beside the crane. The barges would remain along side the laybarge until unloaded, after which it would be towed away prior to the arrival of the next barge. During low tide it would float along side the laybarge in the "bathtub".

A shallow draught anchor handling tug would be required to move the anchors of the laybarge forward. The dredge is expected to employ anchor booms to position her anchors, as shown in Plate 5-3.

517 WORKING AREA

The maximum top width of the dredged trench would be between 75 - 90 m depending on the final side slope and depth of overdredge.

A 200 m wide strip, 100 m either side of the route centre line would be required as a working area, (as shown in Plate 5-1). The extra width being required for positioning anchors.

518 THE INFLUENCE OF CLIMATIC AND MARINE CONDITIONS ON CONSTRUCTION OPERATIONS

.1 Wind

In order to model the influence of severe weather conditions on the project it has been assumed that winds of 9 m/s or greater would halt all marine operations seawards from chainage 3,000 (see Plate 4-4). Based on this, weather downtime percentages for each month of the year have been calculated, and these are shown in the Table 5-1 in (Section 5121.)

The dredge would be the first piece of equipment affected by deteriorating weather conditions. A sea state created by a wind approaching 9 m/s would halt dredging, as the discharge line would start to break apart and the cutter head would oscillate uncontrollably. The smallest unit, the discharge pontoon, would also be affected and the discharge nozzle would need to be raised to prevent it striking the bottom the trench.

The laybarge would be able to continue pipelaying under these conditions, but would soon be stopped by the lack of progress of the dredge. Pipelaying would be able to continue until waves of 2.0 - 2.5 m high occurred, at which stage the pipes would be capped and laid on the bottom to prevent damage to them. Waves of this magnitude could only occur on the foreslope. Therefore it is considered unlikely for this operation to be required, if the landwards construction sequence was adopted, because the work on the foreslope would be carried out during the summer months. On the other hand, if the seawards construction sequences was adopted it would be more likely to be required, as the work on the foreslope would be carried out during the winter months.

.2 Currents

The dredging and laybarge operations would be able to continue in currents of 1 - 1.5 m/s. From the records available, which have been discussed in Section 2.3, tidal currents greater than 1.5 m/s do not occur either offshore of the foreslope or across the intertidal flats. Flow speeds of 1.5 m/s have been recorded in the Canoe Pass channel during the annual freshet. However, construction in Canoe Pass would be carried out after the annual freshet when flow speeds would range from 0.5 - 1.0 m/s. The influence of the tidal currents and channel flow on the operation of the discharge pontoon is discussed in Section 5.5.

.3 Visibility

Because a considerable part of the construction operations would be carried out 24 hours a day, visibility would be an additional factor, which could cause delays. Visibility under one mile (1.6 kilometres) would cause difficulties to the tugs and work boats travelling across the intertidal flats, even though they might have radar. Therefore, personnel, stores or pipe barges could be delayed which might interrupt the progress of the construction train. The visibility during the fall and winter, when the majority of the work would be carried out, is less than one mile (1.6 kilometres) for approximately 10% of the time between 0000 and 1200 hours. The affect of visibility on the construction is more difficult to model, but it would not delay the work by more than 3 or 4% over the total contract period and has been allowed for in the contingency period.

5.2 PROPOSED CONSTRUCTION SEQUENCES

INTRODUCTION

The pipeline can be constructed across Roberts Bank in either an offshore direction from Brunswick Point towards the foreslope (seawards direction) or in an inshore direction from the foreslope towards Brunswick Point (landwards direction). The sequence of marine construction operations for the seawards direction is described in Secton 521 and illustrated in Plates 5-8 and 5-9 and the landwards direction is described in Section 522 and illustrated in Plates 5-10 and 5-11.

Further details of the operations are contained in the following sections:

(i)	Section 5.3	Trench Cross Section
(ii)	Section 5.4	"Bathtub"
(iii)	Section 5.5	Trench Backfill Operation
(iv)	Section 5.6	Shore Approach Trench
(v)	Section 5.7	Dyke Crossing
(vi)	Section 5.8	Hydrostatic Test
(vii)	Section 5.9	Tie-in Between Roberts Bank and Strait of Georgia Sections

521 SEAWARDS CONSTRUCTION SEQUENCE (PLATES 5-8 & 5-9)

Once mobilization has been completed and all equipment and personnel have been assembled, work would begin on the excavation of the pipelines shore approach trench. This ditch would extend approximately 100 m from the dyke at Brunswick Point. The trench would be excavated by track-mounted excavators working from portable spreader mats and a small clamshell dredge could be used for the outer half. The excavated material would be stockpiled either side of the trench. (See Section 5.6 for further details of these operations.)

Concurrent with the excavation of the shore approach trench, the pipelines pulling station would be constructed immediately behind the dyke. A work area of 500 m^2 would be required for one or more winches to be mounted on concrete footings and anchored into the ground.

Once the shore approach preparations had commenced the cutter suction dredge would be towed into Canoe Pass on a high tide. Initially the dredge would dredge a 500 m long trench ("bathtub") in the Canoe Pass channel, extending into the salt marshes until it met the shore approach trench. The 100,000 m^3 of spoil would be transported by scow to an approved dump zone some distance away. When this operation is near completion the laybarge would be moved into position 150 m off the dyke at Brunswick Point, with the stern pointing towards the shore.

Joints of pipe (12 m lengths of pipe), previously coated with concrete weight coating and corrosion coating, would then be transported to the laybarge where they would be welded together, and the welds wrapped and coated. The work would proceed simultaneously on the two pipelines. As the joints are welded the pipelines would gradually be pulled ashore (in the shore approach trench) to the toe of the dyke by the land based winches.

When the pipelines have been pulled ashore, the discharge pontoon would move behind the laybarge and installation of the pipes through the Canoe Pass section would begin. The laybarge would move slowly forward towards the Strait of Georgia, pulling itself forward on its anchors, as it lays the two pipelines on the bed of the dredged trench. The anchors would periodically be advanced by the anchor handling tug. Meanwhile, the cutter suction dredge would excavate the pipeline trench ahead of the laybarge, pumping the excavated material through its submerged discharge pipe to the pontoon located behind the laybarge. The backfill pontoon would progressively deposit the material over the installed pipelines, burying them, and filling in the trench.

Meanwhile the shore pull equipment would be removed and a cofferdam would be constructed around the ends of the pipes to prevent the seawater entering the trench during the cutting through of the dyke. After the dam was completed the dyke would be crossed, and the pipelines laid inshore to the start of the landline section, as described in Section 5-7. Then the dyke would be backfilled, the cofferdam removed, and the shore approach trench backfilled.

After approximately 2.5 kilometres the dredge would move out of the Canoe Pass channel to start the crossing of the intertidal flats. Once the construction train had progressed far enough for the backfill pontoon to pass through the channel bank. The trench would be sealed from Canoe Pass, in order to form the "bathtub", by dumping barge loads of coarse sand across the trench. Approximately 8,000 m^3 of material would be required.

Throughout the operation a survey team would monitor the depth of the trench and the elevation of the pipeline to an accuracy of ±0.5 m by making crossings of the trench with a small boat equipped with a narrow beam echo sounder. Horizontal positioning would be provided by a radio location system providing an accuracy of ±3 m. A laser beam system may also be used for alignment along part of the route. Pipelaying would continue in this manner across the bank to the merger point where the two lines would begin to spread apart in individual trenches. At this point both of the pipelines would be capped and laid onto the bottom of the trench.

The dredge would excavate the north arm trench through the foreslope to the -23 m GSC contour, where the burial of the pipelines finishes. When the main trench has been backfilled to within 200 metres of the merger point the discharge pontoon would be moved to a point south of the pipeline route and the dredgate stockpiled inshore of the foreslope crest. The volume of material which would be stockpiled is estimated to be 50,000 - 100,000 m^3 (an area 100 m x 100 m x 1 m deep), of which 30 - 50% may be carried away by the wave and tidal action. The exact quantity would depend on the prevailing weather conditions, but the material would tend to move to the south in the predominant current direction, and away from the Banks.

During the dredging of the north arm, either the laybarge or suitable work barge would lay two anchors with a sheave attached, at the -45 m GSC contour in line with the trench. When the north arm was completed the dredge would move to the south arm and the laybarge would lay heavy wires from the sheave to the foreslope crest.

On reaching the foreslope crest, the laybarge would anchor with its stern offshore. One end of the wire would be attached to a pulling head on the end of a string of pipe, the other end to a winch, and the pipeline would be winched off the barge. Additional lengths of pipe would be welded on until the pulling head reached the sheave. After the pull was completed the laybarge would move inshore laying the last 550 metres of pipe to the merger point where the pipeline would be capped and lowered into the bottom of the trench. By this time the excavation of the south arm would have commenced. The laybarge could move offshore to position the south arm anchors and sheave, and complete the pipe to the merger point in the same manner as the north arm.

Concurrent with these operations, scows would dump coarse sand across the north arm at the foreslope crest to seal the trench. Then the dredge would start to backfill the north arm using the material stockpiled to the south of the pipeline route.

After the laying of the south arm is complete the laybarge would move to one side of the pipelines at the merger point. Two ends of one of the pipelines would be raised up out of the water. The ends would be trimmed to length, welded together, coated, and lowered back into the bottom of the trench. The procedure would be repeated for the second pipeline.

Meanwhile the South Arm would be sealed by dumping sand from scows across the trench at the foreslope crest, and the backfilling of the trench would be completed. It is estimated that approximately 220,000 m^3 of material would be required to complete the backfilling of the trench, as the result of the removal of material to form the initial "bathtub" and the backfill losses along the length of the route. The remaining stockpiled material would supply approximately one quarter of the required volume, and the balance would be dredged from the foreslope close to the pipeline route.

The lower foreslope trenches would be allowed to backfill naturally, which is expected to take a few months.

Finally, the laybarge would remove the sheave blocks and anchors on the foreslope and the pipelines would be hydrostatically tested with sea water, as described in Section 5.8. On completion of the hydrostatic tests the pipelines would be de-watered and the marine section tied-in to the landline at Brunswick Point. Meanwhile the laybarge would be demobilized, but the dredge would only be demobilized on completion of the backfilling of the trenches.

523 LANDWARDS CONSTRUCTION SEQUENCE (PLATES 5-10 & 5-11)

On the completion of mobilization of all equipment and personnel, work would begin on the dredging of two trenches through the foreslope. The spoil would either be discharged onto a suitable section of the foreslope close to the pipelines or removed by scow to a designated dumping zone some distance away.

The dredge would commence by excavating the South Arm. Meanwhile the laybarge would lay a sheave block attached to two anchors where the South Arm route meets the -45 m GSC contour. After the South Arm is excavated the dredge would move to the north arm and the laybarge would commence to lay heavy wires from the sheave block to the foreslope crest. On reaching the crest, the laybarge would anchor with its stern facing offshore. One end of the wire would be attached to a pulling head on the end of a string of pipe, and the other end attached to a winch, and the pipeline would be winched off the barge. Additional lengths of pipe would be welded on, until the pulling head had reached the sheave block. After the pull was complete the laybarge would move inshore laying pipe to the point at which the two ditches merge. At this point the pipeline would be capped and lowered into the bottom of the trench. In the meantime scows would dump a coarse sand across the south arm trench below the foreslope crest to seal the trench. Approximately 5,000 m^3 of material would be required. Then the excavation of the north arm trench would commence and the dredged material would be used to backfill the south arm trench. Meanwhile the laybarge would move offshore to position the north arm sheave block and install the pipeline to the merger point in the same manner as the south arm. The laybarge would move inshore of the foreslope crest, and scows would dump coarse sand across the north arm trench. The dredging of the inshore section would be commenced and the dredged material used as backfill. The sheave blocks and anchors would be removed at this stage by an auxiliary work barge.

When the laybarge reaches the merger point for the second time following the laying of the north pipeline the previously laid south pipeline would be picked up, and both lines prepared for laying across the intertidal flats. The lower foreslope trench would be left to backfill naturally, which is expected to take a few months.

On completion of the section through the foreslope the laybarge would move slowly towards Brunswick Point, pulling itself forward on its anchors, and laying the two pipelines approximately 3-5 m apart on the bed of the dredged trench. The anchors would periodically be advanced by the anchor handling tugs. Meanwhile, the dredge would excavate the pipeline trench ahead of the laybarge, pumping the excavated material through its submerged discharge pipe to the discharge pontoon located behind the laybarge. The discharge nozzle would deposit the material over the installed pipelines burying them and backfilling the trench.

Throughout the operation a survey team would monitor the depth of the trench and the elevation of the pipeline to an accuracy of ±0.5 m by making crossings of the trench with a small boat equipped with a survey echo sounder. Horizontal positioning would be provided by a radio location system providing an accuracy of ±3 m. A laser beam system may also be used for alignment along part of the route.

Pipe laying would continue in this manner across the bank and into Canoe Pass. Prior to breaking through the side of Canoe Pass Channel, bottom dumping scows would place sand across the trench to seal the intertidal flats section. Once the complete train has passed through into Canoe Pass, a second seal would be formed across the trench by the same method.

The laybarge would stop laying pipe 500 m from the dyke at Brunswick Point, and the pipelines would be capped and lowered into the bottom of the trench. The dredge would continue to excavate the trench until approximately 100 m from the dyke.

The final 100 m of trench would have been excavated by track-mounted excavators working from portable spreader mats and a small clamshell dredge. The excavated material would be stockpiled either side of the trench (see Section 5.6 for further details of these operations). Concurrent with the excavation of the shore approach trench, the pipelines pulling station would be constructed immediately behind the dyke. A work area of 500 m^2 would be required for one or more winches to be mounted on concrete bases and anchored into the ground.

Once the shore approach preparations were complete the laybarge would turn around, so that the stern was facing towards the dyke. Two more strings of pipe would be prepared which would gradually be pulled ashore by the winches through the shore approach trench to the toe of the dyke. The laybarge would then move offshore laying the pipelines back to a point where they can be tied-in with the pipelines previously laid inshore from the foreslope. The two pipelines would be lowered to the bed of the trench and the laybarge would move to one side. The two ends of one line would be winched aboard the side of the laybarge, the ends would be trimmed to length, welded together, coated and lowered back into the trench. The procedure would be repeated for the second pipeline.

Meanwhile the shore pull equipment would be removed, and a cofferdam constructed around the ends of the pipes to prevent the sea water entering the trench during the crossing of the dyke and during the hydrostatic test. Then the dyke would be crossed, and the pipelines laid inshore to the start of the landline by a land pipeline spread, as described in Section 5-7.

After the tie-ins are completed the pipelines would be hydrostatically tested with sea water as described in Section 5-8.

Then the backfilling of the trench in Canoe Pass would be completed using the material dredged from local sand bars to the south of the route, close to Brunswick Point. The volume of material required to complete the backfilling of the trench would be approximately 220,000 m^3. This requirement would have been generated by the removal of material at the foreslope to form the "bathtub" and by the losses of backfill volume along the length of the route.

Finally the dyke crossing would be backfilled, the shore approach trench backfilled with stockpiled material, and the cofferdam removed.

5.3 TRENCH CROSS SECTION

The material which comprises Roberts Bank has the characteristics of a fine/medium sand with a small percentage of silt, as described in Section 3. The trench would be excavated by the cutter suction dredge in a series of box cuts. (Plate 5-12.) The trench would be dredged with a 20 m bottom width and would be overdredged by approximately 1 metre in depth to allow for slumping of the sides and filling in prior to installation of the pipe. The maximum trench depth would be approximately 8.6 m.

It would be 6 - 10 days before the construction train would have advanced a sufficient distance for the pipes to be laid. During this period the slopes of the trench would slump to approximately one in five, and the overdredge fill in. The bottom width would reduce to approximately 10 m, and the trench cross section would approximate to the solid line in Plate 5-12. The maximum top width of the trench would be between 75 and 90 m.

The cross sections described would only apply where the "bathtub" is effectively sealed, so that no drawdown is created in the slopes from tidal effects. When within, breaking into or out of Canoe Pass, and at the foreslope, the "bathtub" would not be sealed, and flatter slopes can be expected.

At the foreslope and within the Canoe Pass channel the trench would be subject to bed movement due to wave and current action. This is expected to cause the trench to backfill more rapidly. Therefore to ensure the pipe is laid with sufficient cover in these areas overdredging of 1.5 - 2 m would be required. Trench cross sections within Canoe Pass and through the foreslope are shown in Plate 5-13.

The cross sections in Plates 5-12 and 5-13 have been used for the purpose of calculating the quantity of dredge material to be excavated. However, the contractor would be responsible for ensuring that the pipelines are laid to the correct burial depth, and the excavated profile might have to be adjusted as actual infilling rates are noted.

5.4 "BATHTUB"

The "bathtub", or construction trench, would be of sufficient length to contain the dredge, laybarge, and discharge pontoon. The minimum length has been estimated as 400 m, and the length of the initial "bathtub" dredged at the commencement of construction would be of this order. As the "bathtub" moves along the route through Canoe Pass and across the intertidal flats the length of the "bathtub" would vary. Any losses of the dredged material during the backfilling of the trench would increase the length, while an increase in trench depth would shorten the "bathtub" as a result of the increase in volume dredged per metre. The reverse would occur when the trench depth decreased.

For the majority of the route the material dredged would have a silt and clay content less than 10%. However, locally thin layers of silty sand and sandy silt would be encountered which would have silt and clay contents between 10 and 25%.

Where the material has a silt and clay content of 10% or less, the dredgeate losses would have no appreciable effect on the bathtub size due to the voids that would occur in the backfilled material (bulking). Therefore, in order to estimate the variation in "bathtub" size across the Bank, a nominal loss in backfill volume of 5% has been assumed, although the actual loss of material may be closer to 5-10% of the total dredged volume. The influence of the loss in volume and the various features along the route, on the length of the "bathtub" for the two construction sequences, are shown in Plate 5-14.

The locations of the seals at the approaches to the foreslope and the Canoe Pass channel to maintain the integrity of the "bathtub", and to retain the backfilled material are also shown in Plate 5-14. These seals would be constructed from a coarse sand or fine gravel (2 mm to 20 mm well sorted), and dumped across the construction trench by bottom dumping scows. The volume required for each of the seals has been estimated as approximately 5000 m^3 on the lower foreslope and 8000 m^3 on the intertidal flats. The total volume of material required for the seawards construction sequence would be 18,000 m^3 and for the landwards construction sequence would be 26,000 m^3.

The landwards construction sequence has two seals in the intertidal section. The first seal would be constructed at a point 500 m from the edge, before the dredge had broken into the Canoe Pass Channel. It would act as a protective barrier to the already backfilled trench when the dredge opens up the "bathtub" into Canoe Pass. The second seal would be placed once the construction train has passed into Canoe Pass, and would act as a barrier to the migration of Canoe Pass along the pipeline route. The profile of the bank of Canoe Pass Channel bank would be allowed to reform naturally.

5.5 TRENCH BACKFILL OPERATION

INTRODUCTION

The backfill operation consists of discharging the dredged material into the trench to bury the pipes and return the area to its original level. During any discharge operation losses occur, and the aim is to keep them to a minimum to avoid having to import large quantities of new material. It is the finer particles in the dredgate which are lost, and generally these losses do not exceed the percentage of material finer than 0.075 mm. Therefore from Table 3-1 it can be seen that the overall percentage of bank material that might be lost would be approximately 19%, if no special precautions were taken. However, it is envisaged that the losses could be reduced to 5-10% of the volume dredged by keeping the discharge nozzle below local bank level and out of the path of tidal currents.

The discharge pontoon (Plate 5-7) would operate under two different conditions. The first would be across the intertidal flats, as described in Section 551, and the second would be within Canoe Pass channel, as described in Section 552.

To backfill the trench the discharge pontoon would be moved sideways across the trench by means of side anchors. The backfill would be deposited over the trench to give a small (0.5 m) hump. Care would be taken across the intertidal flats to ensure that the small channels that traverse the trench were not blocked or diverted.

551 BACKFILL OPERATION ACROSS INTERTIDAL FLATS

From Plate 2-10, it has been estimated that the water level would be low enough to isolate the "bathtub" for approximately 5% of the time. During this period the discharge nozzle would be in the raised position (horizontal) to permit the backfill material to be deposited as high as possible, as shown in Plate 5-15, Sequence A. The "bathtub" would be isolated, so no losses of material would occur.

As the tide rises the nozzle would be lowered to keep it between 0.5 - 1.0 m below the adjacent bank level (Plate 5-15, Sequence B.) The tidal currents would flow across the still water of the "bathub" and cause some movement at a lower level. It is envisaged that at the lower level speeds would be approximately half the full tidal currents and the discharged material would settle within the bathtub at some point away from the discharge nozzle.

A splash plate fitted to the nozzle would reduce the impact velocity of the discharge on the trench bottom, and therefore reduce the muddiness or turbidity of the water in the bathtub. A similar effect may be achieved by using a conical expansion nozzle to reduce the exit velocity of the discharged material. The lower turbidity would reduce the quantity of suspended material that could reach the upper layers of the "bathtub", where the currents would carry them out of the trench. The majority of the dispersal of the backfill material would be completed with the discharge nozzle in this position. It is considered that a submerged exit fitted with either of the nozzles described would reduce losses to around 5%.

However, with the nozzle in the lowered position, the discharge pontoon would only be able to backfill the trench to some height below the local bank level. Therefore for part of the time the discharge nozzle would have to be raised some distance above the adjacent bank level, (Plate 5-15, Sequence C.) It has been estimated that the nozzle would need to be in this raised position for approximately 3-4 hours/day during high tide, in order to complete the backfilling of the trench. During this operation the greatest losses of dredgate would occur, and are estimated to be between 10 - 25% depending on the silt content of the sediment. The dispersion of these losses is described in Section 6.5.

The total volume lost during construction in the intertidal flats would be 85 - 120,000 m^3.

552 BACKFILL OPERATION IN CANOE PASS CHANNEL

While within Canoe Pass channel, the discharge nozzle would be below the water level all the time, and the discharge plume would be continually influenced by the channel flow. The peak flow velocities anticipated during construction are 0.5 - 1.0 m/s in the downstream direction and 0.3 - 0.6 m/s in the upstream direction. The discharge nozzle would be positioned to suit the direction and strength of the flow so that the discharged material would be carried into the trench. (Plate 5-16.) It is envisaged that between 5 - 10% of the material would be lost and deposited within Canoe Pass. The total loss would be 45,000 - 90,000 m^3.

553 SUMMARY OF DREDGATE LOSSES

Location	Tide	% Time	% Losses	Quantity (000 m^3)
Intertidal Flats	Low	5%	0	
Intertidal Flats	Medium	80%	5	
Intertidal Flats	High	15%	10 - 25	
Intertidal Flats	All	100%	5 - 7	85 - 120
Canoe Pass	All	100%	5 - 10	45 - 90
Overall	All	100%	5 - 8	130 - 210

5.6 SHORE APPROACH TRENCH

INTRODUCTION

The pipelines would be brought ashore at Brunswick Point through an area of tidal marsh. The pipelines would be pulled ashore from the laybarge anchored approximately 150 m offshore from the dyke, into the shore approach trench, and through the marsh. The depth of cover to the pipelines would decrease from 7.0 m at the edge of Canoe Pass to 2.0 m at the toe of the dyke, and the trench width would reduce correspondingly from 85 m to 25 m. (Plate 5-17.) Typical trench cross sections are shown in Plate 5-18.

The areas of marsh that would be destroyed or disturbed are tabulated below:

Chainage	Area Destroyed (m^2)	Area Disturbed (m^2)
0.0 - 100.0 m	2,750	8,875
100.0 - 200.0 m	5,750	5,515
	8,500	14,390

561 DYKE TO CHAINAGE 100 m

The trench would have a bottom width of 5 m and side slopes of one in three. The trench would be subject to tidal action, but it is envisaged that the side slopes would remain at 1 in 3 to 1 in 5, for long enough for the pipelines to be pulled ashore.

The trench would be over excavated by approximately 0.5 m to allow for any sloughing of the trench sides.

The excavated material would be stockpiled either side of the trench for use later as backfill. Where possible the top layer containing roots would be excavated and stored separately in order that it could be replaced on top. The spoil heaps would be subject to tidal action during the period between excavation and completion of the backfill. The heaps of material would spread outwards and the finer material would be carried away into Canoe Pass by the channel flow and tidal currents. It is envisaged that some 10 - 15% of the material would be lost and would need be replaced by importing a similar material either by scow or by trucks to the edge of the dyke. The volume that would be required is approximately 500-1,000 m^3.

It is envisaged that the trench would be excavated and backfilled by a combination of land based excavators and a small clamshell dredge. The types of land based excavators that would be suitable include back-hoes, drag lines and clamshells. A back-hoe and a clamshell are shown in Plate 5-19. For operation in a marsh environment they could either be mounted on standard caterpillar tracks, or on extra wide tracks. In the former case, portable spreader mats made of heavy timber would be required to support the unit on the marsh and the extra operation of moving the spreader mats would reduce the output of the excavator. In the latter case, the extra wide tracks would reduce the ground pressure to allow the equipment to move over the marsh safely. The units in Plate 5-19 are both fitted with extra wide tracks mounted on amphibious pontoons. The main advantage of the amphibious unit is that it can continue operating in water depths up to 1 m, at which point it commences to float. In a tidal area this would permit the excavator to work longer shifts than a standard unit which would need to travel inshore as the tide rose.

The small crane clamshell dredge would consist of a crane fitted with a clamshell and mounted on a barge small enough to float in the excavated trench. A small clamshell dredge is shown in Plate 5-20.

The backfill operation would be completed with the same equipment. The imported backfill would be brought in before the final layer of excavated material was replaced to ensure the uniformity of the top layer with adjacent areas. The finished level would be within approximately ±0.3 m of the original level.

The work area required would be 120 m wide as shown on Plate 5-17 and 5-18, and it is envisaged that the excavators and the spoil could be contained within this area.

It is estimated that excavation of the trench would take approximately 17 days, then pulling the pipes ashore would take approximately 5 days, and backfilling would take approximately 14 days. After an allowance is included for contingencies, then a total duration of work of 45 days would be envisaged. No allowance has been made for any replanting or reseeding that might be required.

562 CHAINAGE 100 m TO THE EDGE OF CANOE PASS

This section of trench would be excavated by the cutter suction dredge, because it is considered to be uneconomical to excavate a trench of this depth (5.6-7.6 m) by any other means. The technique would effectively destroy approximately 7000 m^2 of the vegetated layer of the tidal marsh. The hydraulic dredge would work from the outer edge of the marsh towards the dyke, and is expected to overlap with the clamshell dredge at approximately the 100 m chainage point.

5.7 DYKE CROSSING

At Brunswick Point, the marine sections of the pipelines are pulled ashore in a trench through the tidal marsh to the toe of the dyke.

Plate 5-21 shows the sequence of operations in crossing the dyke. On completion of the pull ashore (Sequence 1), cofferdam would be constructed around the end of the pipes (Sequence 2) to prevent the sea water entering the trench while the dyke is being cut through and during the hydrostatic test. Pumps would be used to keep the inside of the cofferdam dry, and the water from the pumps would be discharged onto the marsh.

A trench would be cut through the dyke extending into the shore approach trench (Sequence 3) and the spoil stockpiled.

Joints of pipe would then be lifted into the trench and welded onto the marine pipelines until they had been extended inshore to the start of the landline (Sequence 4). Seepage collars would be installed on the lines in this section. After completion the pipelines would be hydrostatically tested.

The trench would be backfilled and the dyke restored to its original profile. (Sequence 5).

On completion of the restoration of the dyke, the shore approach trench would be backfilled, the cofferdam removed, and the bank restored to its original condition (Sequence 6).

An alternative technique for crossing the dyke would be to build the cofferdam on the inside of the dyke and pull the pipelines in one operation through the dyke from the laybarge. However, this has several disadvantages:

(i) The ends of the pipes would not be readily accessible for the hydrostatic tests or the tie-ins to the landlines, until the dyke had been re-built. This could delay the demobilization of the expensive marine equipment.

(ii) The area within the cofferdam would be contaminated by seawater and the topsoil would have to be removed and replaced by new material.

(iii) The increased area of land required inside the dyke would interfere with construction of the valve and pigging station immediately behind the dyke.

(iv) Installation of the seepage collars becomes more difficult.

5.8 HYDROSTATIC TEST

Upon completion of the installation each pipeline would be hydrostatically tested, as follows:

(i) Pig launchers would have been fitted to the foreslope ends of the pipelines, with gauging pigs installed inside. A pipeline pig is a fluid driven, non-tethercal traveller, that passes through a pipeline. They are used to gauge and clean the pipelines before commercial liquids or gases are allowed to enter, and for routine cleaning and inspection during the lifetime of the pipelines. A gauging pig is one equipped with a thin circular plate, slightly smaller in diameter than the inside of the pipe. It is used to verify that the pipe is round and free of dents or buckles. Typical pipeline pigs are shown in Plate 5-22.

Water, which may include a biodegradable corrosion inhibitor, would be pumped in behind the gauging pig which would be pushed through the pipeline by the water.

(ii) The pipeline would be full of water when the pig reached Brunswick Point. Then the pig would be removed and the gauging plate examined for damage.

(iii) Meanwhile, the second line would be filled with water in a similar manner.

(iv) Each pipeline in turn would be pressurized to the test pressure of 1.25 times the pipeline operating pressure and held for 24 hours.

(v) Upon satisfactory completion of the test the pressure would be released by opening the valve at the foreslope end.

(vi) Each line would be dewatered by pushing a general purpose pig with compressed air from the Brunswick Point end to the foreslope. The total volume of water to be expelled on the foreslope would be 1.23 million litres per pipeline for the 406 mm diameter pipeline.

5.9 TIE-IN BETWEEN THE ROBERTS BANK AND STRAIT OF GEORGIA SECTIONS

The pipelines would be laid across the Georgia Strait by a deep water laybarge, which is a large purpose built laybarge, similar to a shallow water one, but with heavier, more sophisticated equipment and a higher production rate. The laybarge would commence on the east side of Valdes Island and would lay one pipeline at a time across the Strait along the sea bed and up the foreslope to the -35 m GSC contour. At this point the line would be capped and lowered to the sea bed. The laybarge would then return to Valdes Island to lay the second pipeline across the Strait. Upon completion of this second line, both lines would be hydrostatically tested and de-watered as described in Section 5.8. The volume of the inhibited water which would be expelled at the foreslope would be 4.2 million litres per pipeline.

The deep water laybarge would then anchor at approximately the -40 m GSC contour to one side of the pipelines. Divers would then attach cables to the ends of both sections of one line, and the barge's winches would lift them out of the water alongside the barge. Once alongside the ends would be cut off, prepared, welded together, and the welds x-rayed and coated. The completed pipeline would then be lowered to the sea bed. The pipeline would make a small loop to one side of the route to compensate for the increase in length required during the raising of the pipelines to the surface for jointing. The laybarge would then move over to the second line and the procedure would be repeated.

5.10 CONSTRUCTION SCHEDULES

5101 IMPACT OF WEATHER CONDITIONS

The impact of the seasonal variations in weather conditions on the two construction sequences was modeled through increasing the time for each operation occurring seawards of chainage 3000 m (Plate 4-4), by a weather downtime percentage. The weather downtime for each month of the year is given in the following table:

Table 5-1:

Percentage Weather

Downtime by Month

Month	Weather Downtime
July	10%
August	10%
September	10%
October	15%
November	20%
December	25%
January	25%
February	20%
March	20%
April	15%
May	10%
June	10%

The weather downtime percentage is the percentage time that construction would be halted due to unfavourable weather conditions in an average year. It was assumed that winds greater than 9 m/s would halt construction due to the resulting sea state. The table of weather downtime percentage was prepared from Tables 1-4 and 1-5 which show the percentage time that the wind speed exceeded 9 m/s at Tsawwassen Ferry and Sand Heads Lighthouse between 1967 and 1979. However, in a bad weather year, downtimes could be double those of the average year.

It was assumed that all operations landwards from chainage 3000 m would be unaffected by weather conditions due to the sheltered location, and shallow water.

5102 START DATES

The operations that would be most influenced by the weather conditions are those to be carried out on the foreslope. The best time of year to perform these operations would be during the summer months, when the percentage downtime is a minimum (Table 5-1). As a result the optimum start date for the seawards construction sequence would be in March or April, so the outer section of the intertidal flats and the foreslope section would be completed in June, July and August. For the same reason, the best start date for the landwards construction sequence would be in May or June. These start dates would result in the construction being carried out during the period that the Ministry of Fisheries generally prohibit dredging in the Fraser River. Therefore for the Seawards construction Sequence, which would commence within Canoe Pass, the earliest date that dredging could start was put back to 1st July. While for the Landwards construction sequence, which finishes in Canoe Pass, it was considered more important to ensure that dredging was completed by 28th February to avoid the fry migration downriver.

It is not considered feasible to construct the lines over two seasons because of the difficulty of restarting after a five-month shutdown. Whatever trench had been left open at the end of the first season would have largely sloughed in by the time operations were restarted. This would necessitate exposing the lines using a similar technique to that required for a pipeline repair, as described in Section 5.10. This would be expensive, time consuming, and involve risking damage to the pipes. Therefore to reduce the risk of overrunning 28 February, as a result of a major mechanical breakdown worst than anticipated weather, or labour disputes, a 60 day contingency period has been introduced between the estimated completion date and 28 February. A start date of 15 June was arrived at by working backwards through the construction schedule activities.

5103 SCHEDULE CRITERIA

(i) Dredging would be carried out 24 hours per day, 7 days per week.

(ii) Laybarge would operate for 12 hours per day, 7 days per week and would be able to lay pipe at a rate not less than the progress of the dredge.

(iii) Laybarge would operate 24 hours per day, 7 days per week for positioning of the sheave blocks, for the pulls, and for the tie-ins.

(iv) The schedules have been based on a dredge with a 660 mm (26 inch) diameter discharge with a rated maximum production of 1500 m^3/hr. (Plate 5-5.) For the past few years, there have been at least two dredges of this capacity based in Vancouver.

(v) Due to the nature of the dredging operation and the number of moves required, it has been assumed that the average daily production would equal 14 hours peak production, or 21,000 m^3 per 24 hour day.

(vi) An allowance for weather downtime has been made in accordance with section 5121.

(vii) No contingency has been included for either major mechanical failure, or for weather conditions worse than the average year, as these factors are unquantifiable.

(viii) The foreslope trenches would be excavated using a cutter suction dredge with an extended ladder able to reach 30 m below the water level. The average daily production would equal approximately 10 hours of maximum production, or 15,000 m^3 per 24 hour day.

(ix) The work on land would be carried out by crews working one 10 hour shift per 24 hour day, 6 days per week.

(x) The shore approach trench would be excavated by land based excavators and a clamshell dredge working tidal shifts.

5104 SCHEDULES

The schedule for the seawards construction sequence is shown in Plate 5-23. The total installation time by this sequence is 214 calendar days which includes 33 days for weather downtime.

The schedule for the landwards construction sequence is shown in Plate 5-24. The total installation time by this sequence is 199 days which includes 15 days for weather downtime. In addition, a 60 day contingency period is shown before the start of the presumed prohibited period.

Mobilization and demobilization would add a further 130 days to each contract period making a total of 344 days for the seawards construction sequence and 389 days for the landwards construction sequence.

A larger dredge, for example a 900 mm (36 inch) diameter dredge with a maximum production of 3,800 m^3/hr would reduce the dredging time by 30-50%. This would reduce the total installation times by 50-70 days.

The mobilization of such a dredge would be more costly, and to our knowledge, there are at present only three 900 mm (36 inch) diameter dredges in Canada. One has recently been moved to the West Coast for the expansion of the Westshore Coal Terminal. However, it is not certain that this dredge would still be in the area, and uncommitted at the required time for this project.

5.11 PROJECT COST ESTIMATES

It has been estimated that the construction cost for the seawards sequence starting on 1st July would be $19.1 million and for the landwards sequence starting on 15th June it would be $18.3 million. In both cases, the pipe itself would cost an additional $3 million.

If a 900 mm (36 inch) dredge were available on the west coast, then using it would probably reduce the overall project cost, as the higher daily cost of such a machine would be offset by the reduction in laybarge days. However, these machines are extremely scarce, and it might be necessary to transport one from the East

Coast of Canada, or possibly import one from outside Canada. In that case, the mobilization cost would offset much of the savings arising from the higher production rate.

5.12 COMPARISON OF CONSTRUCTION SEQUENCES

The landwards construction sequence has been nominated as economically and technically preferred over the seawards sequence for the following reasons:

(i) It is $0.8 million cheaper, assuming 15 June start date for the landwards and an 1 July start date for the seawards.

(ii) The foreslope operations would be carried out during the summer months when the better climate and marine conditions prevail.

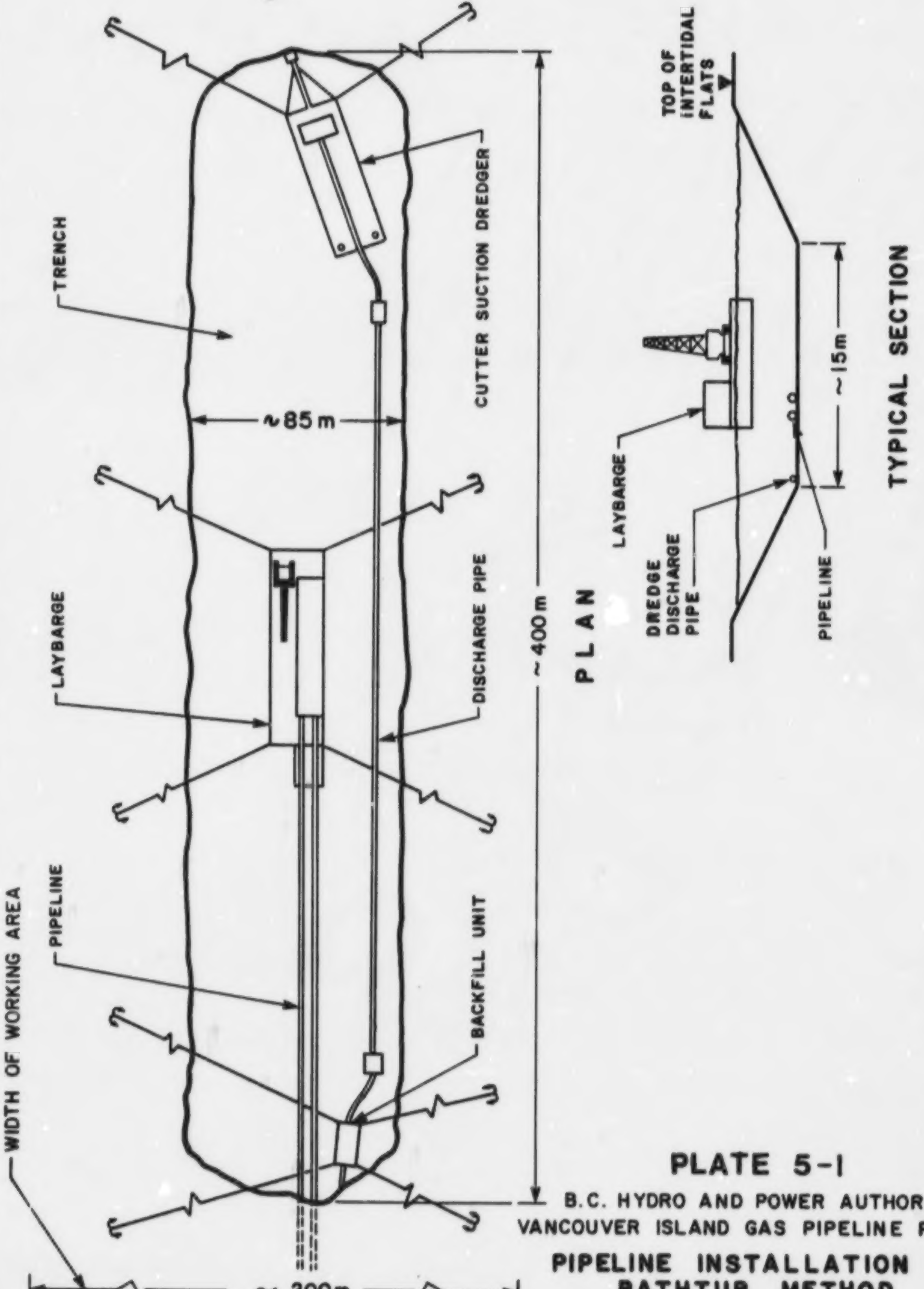
(iii) There is no requirement for removing large quantities of material by scow at Brunswick Point.

(iv) There is no requirement to stock pile material on the foreslope.

(v) As presently planned, the tie-in to the Georgia Strait section would be better scheduled. The seawards sequence would cause the demobilization of the deepwater laybarge to be delayed.

(vi) The amount of fine material carried onto the tidal marshes would be marginally less, because the bathtub would be between the discharge nozzle and the marshes, and would collect some of the material.

MONENCO PIPELINE CONSULTANTS LTD.



TRENCH
CUTTER SUCTION DREDGER
~85 m
LAYBARGE
DISCHARGE PIPE
~400 m
PLAN
PIPELINE
BACKFILL UNIT
WIDTH OF WORKING AREA
~200m
TOP OF INTERTIDAL FLATS
~15m
TYPICAL SECTION
LAYBARGE
DREDGE DISCHARGE PIPE
PIPELINE

PLATE 5-1

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

PIPELINE INSTALLATION BY BATHTUB METHOD
(SCHEMATIC REPRESENTATION)

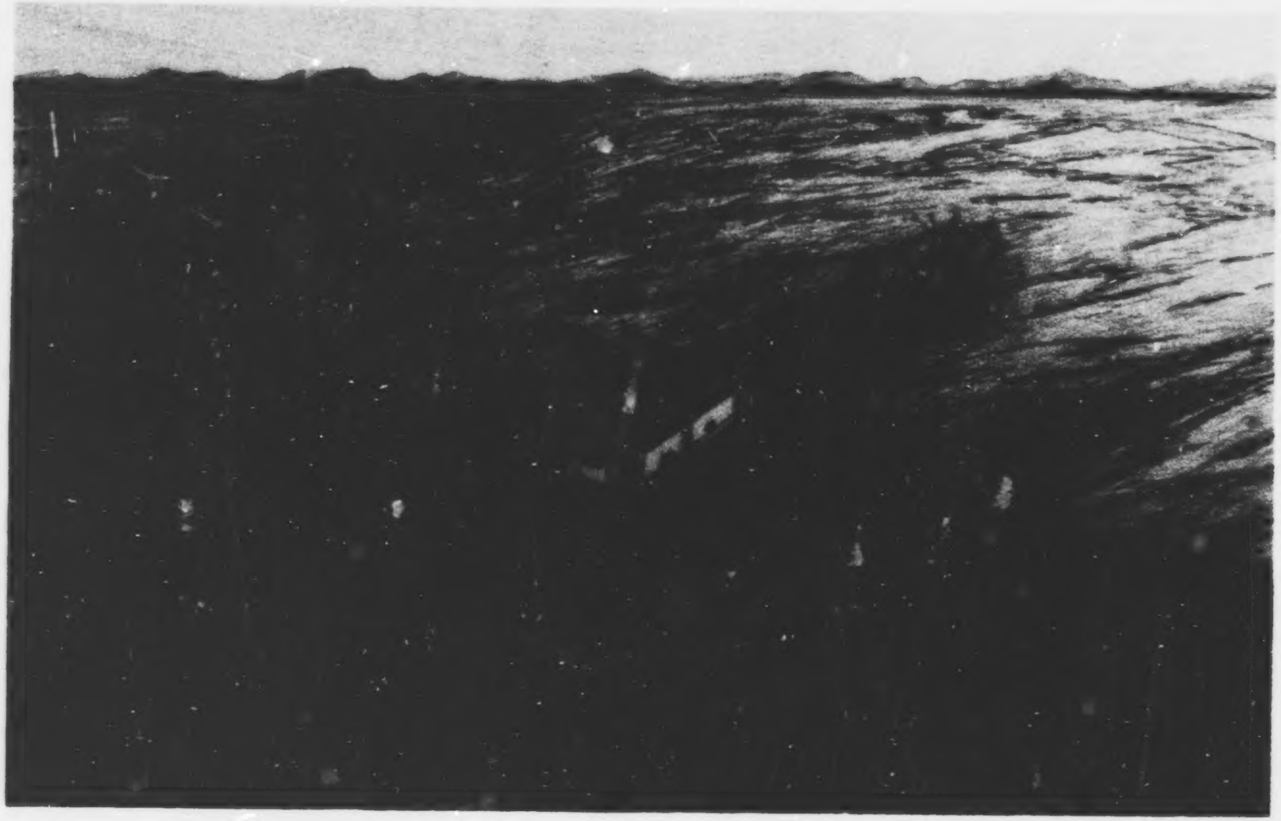


PLATE 5 - 2
B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

PIPELINE INSTALLATION BY
BATHTUB METHOD

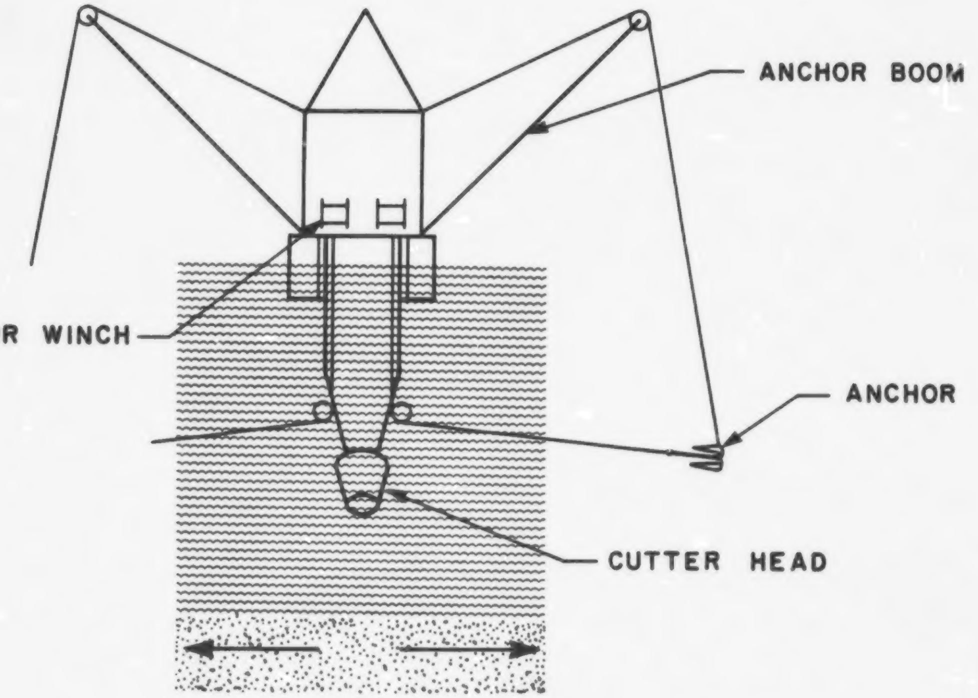

ANCHOR BOOM
ANCHOR WINCH
ANCHOR
CUTTER HEAD

PLATE 5-3

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

CUTTER SUCTION DREDGE
SIDE ANCHOR OPERATION

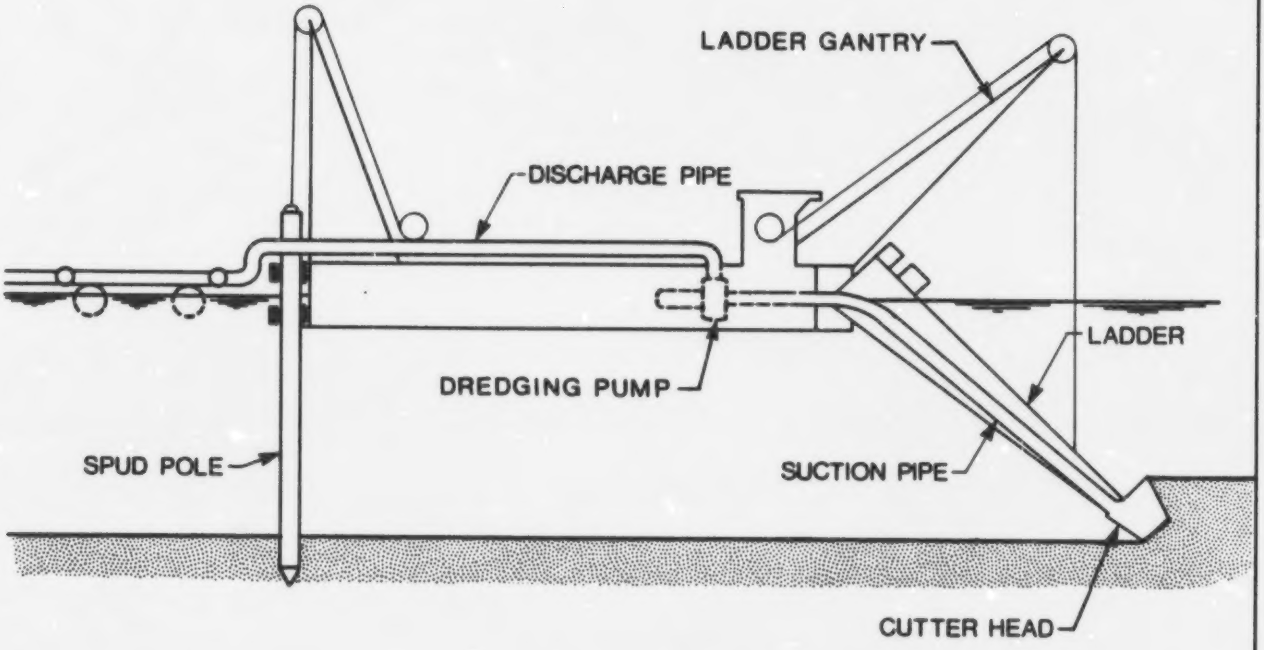
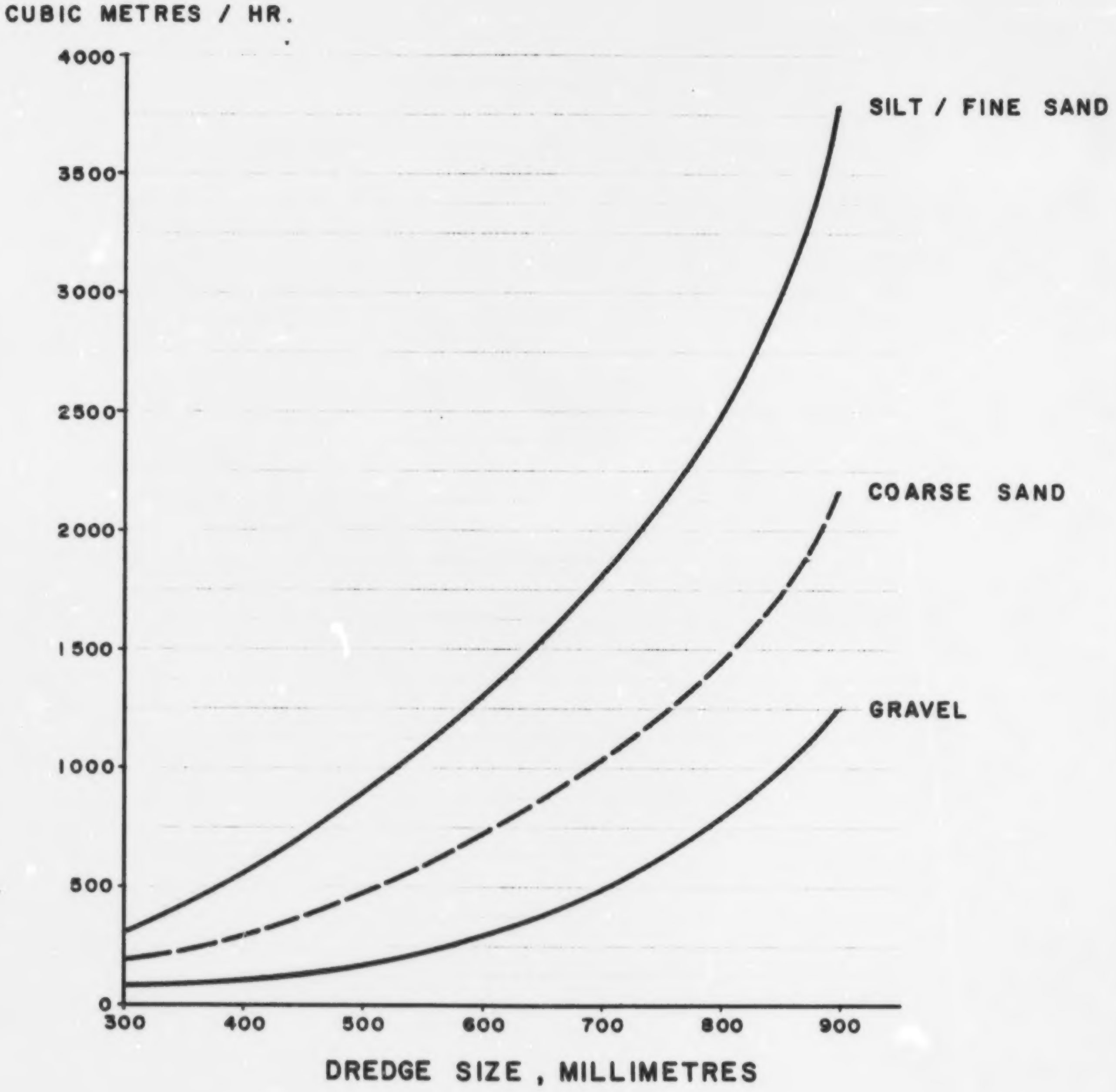

LADDER GANTRY
DISCHARGE PIPE
LADDER
DREDGING PUMP
SPUD POLE
SUCTION PIPE
CUTTER HEAD

PLATE 5-4

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

CUTTER SUCTION DREDGE
SCHEMATIC PROFILE



DISCHARGE PIPELINE
500 — 1000 METRES LONG

PLATE 5-5

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

TYPICAL CUTTER SUCTION DREDGE PRODUCTION RATE FOR VARIOUS SOIL CHARACTERISTICS

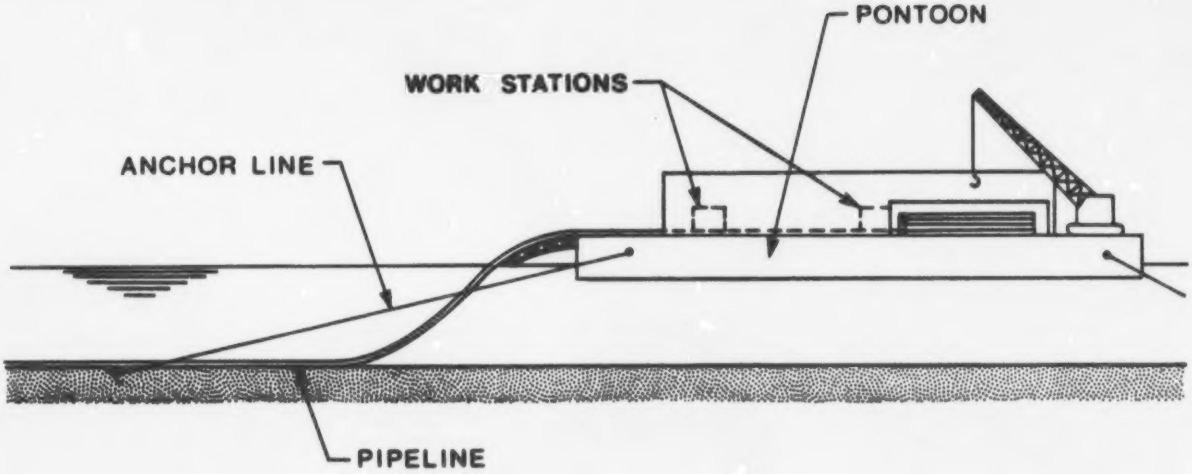
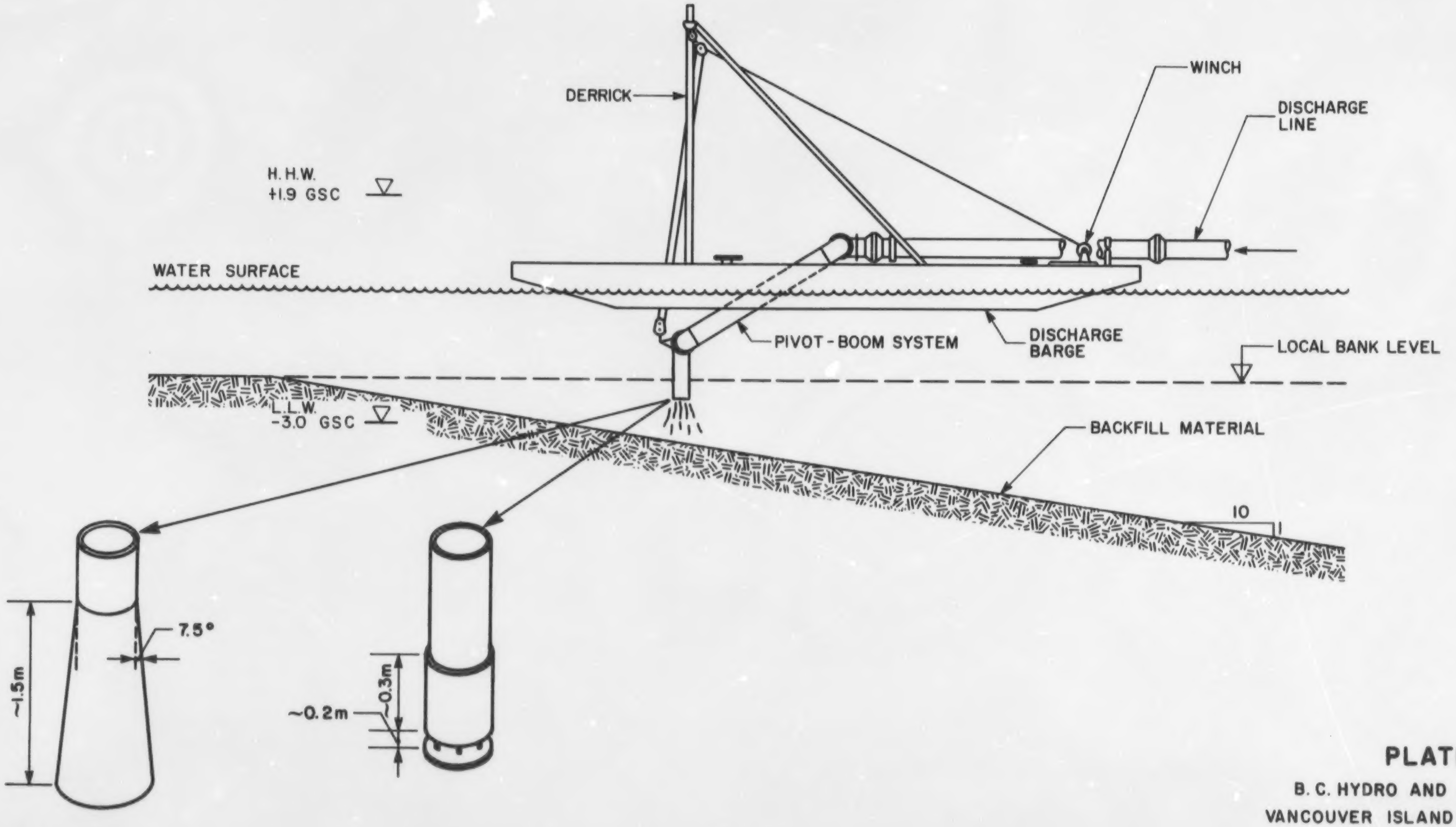

PONTOON
WORK STATIONS
ANCHOR LINE
PIPELINE

PLATE 5-6

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

SHALLOW WATER LAYBARGE
SCHEMATIC PROFILE


DERRICK
WINCH
DISCHARGE LINE
H.H.W.
+1.9 GSC
WATER SURFACE
PIVOT - BOOM SYSTEM
DISCHARGE BARGE
LOCAL BANK LEVEL
L.L.W.
-3.0 GSC
BACKFILL MATERIAL
10
1
~1.5m
7.5°
~0.2m
~0.3m

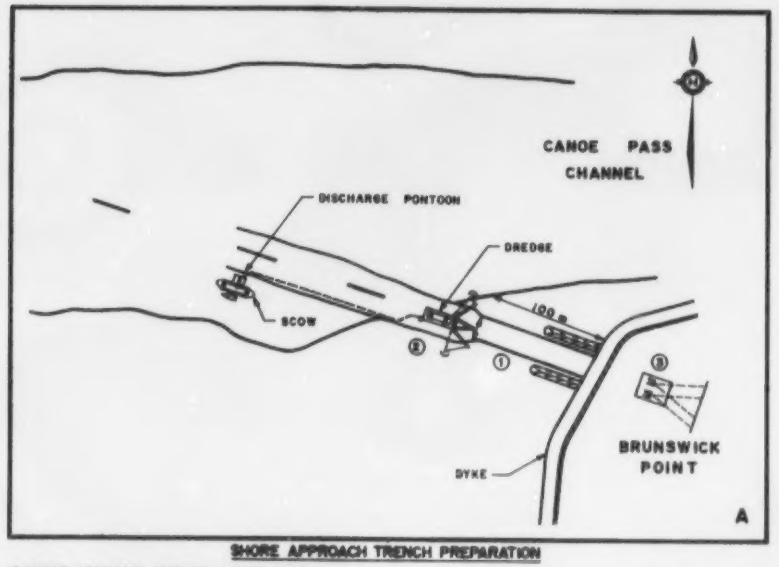
A. DIFFUSER NOZZLE

B. SPLASH PLATE

PLATE 5-7

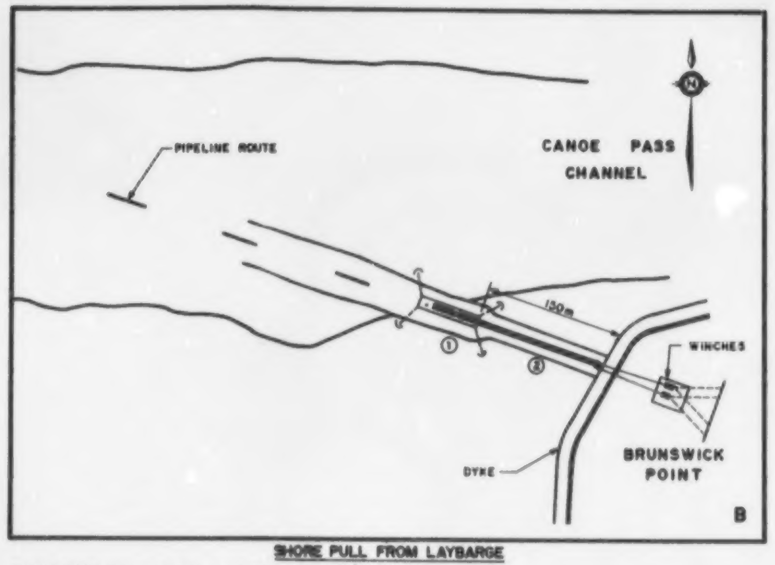
B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

DISCHARGE PONTOON


CANOE PASS CHANNEL
DISCHARGE PONTOON
DREDGE
SCOW
100 m
①
②
③
DYKE
BRUNSWICK POINT
A

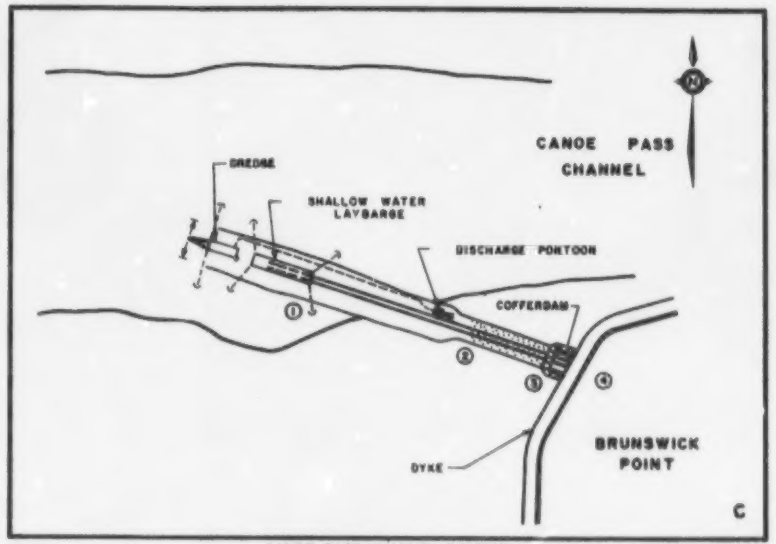
SHORE APPROACH TRENCH PREPARATION

1) SHORE APPROACH TRENCH IS EXCAVATED.
MATERIAL IS STOCKPILED EITHER SIDE OF TRENCH.
2) "BATHTUB" EXCAVATED BY CUTTER SUCTION DREDGE.
MATERIAL IS DISCHARGED INTO SCOWS AND REMOVED.
3) SHORE PULL WINCHES ARE SET UP.


CANOE PASS CHANNEL
PIPELINE ROUTE
150m
WINCHES
①
②
DYKE
BRUNSWICK POINT
B

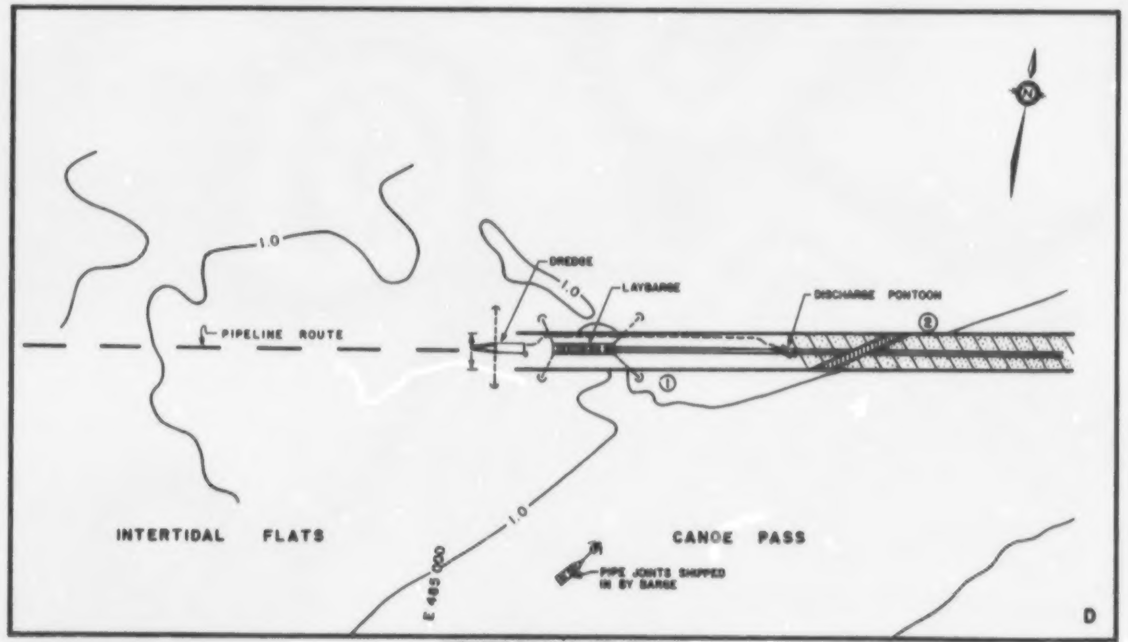
SHORE PULL FROM LAYBARGE

1) LAYBARGE SETS-UP 150m OFFSHORE OF DYKE.
2) PIPESTRINGS ARE PULLED ASHORE.


CANOE PASS CHANNEL
DREDGE
SHALLOW WATER LAYBARGE
DISCHARGE PONTOON
COFFERDAM
①
②
③
④
DYKE
BRUNSWICK POINT
C

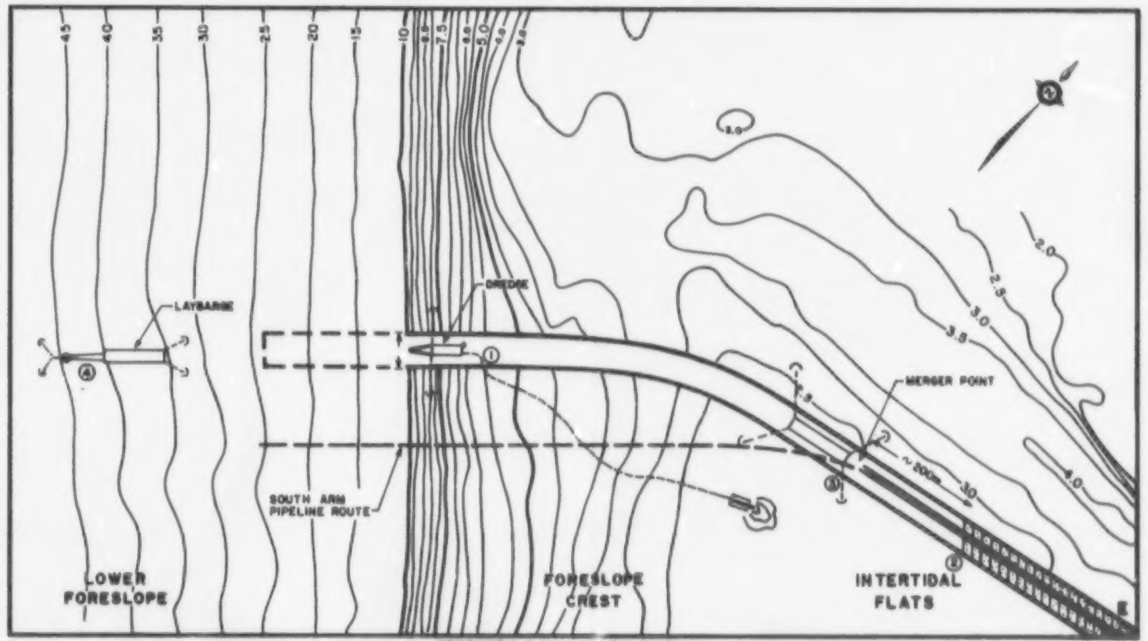
CANOE PASS CHANNEL SECTION

1) DREDGE EXCAVATES TRENCH AND LAYBARGE
FOLLOWS LAYING TWO PIPELINES.
DISCHARGE PONTOON FOLLOWS BEHIND
LAYBARGE BACKFILLING TRENCH.
2) SHORE APPROACH TRENCH IS BACKFILLED.
3) COFFERDAM IS CONSTRUCTED AT
DYKE (SEE PLATE 5-21).
4) SHORE PULL WINCHES ARE REMOVED.


1.0
DREDGE
LAYBARGE
DISCHARGE PONTOON
PIPELINE ROUTE
①
②
INTERTIDAL FLATS
CANOE PASS
E 485 000
PIPE JOINTS SHIPPED IN BY BARGE
D

INSHORE TIDAL FLATS SECTION

1) CONSTRUCTION TRAIN MOVES THROUGH BANK OF CANOE PASS CHANNEL.
2) SAND IS DUMPED FROM SCOWS ACROSS CONSTRUCTION TRENCH TO SEAL IT.


45
40
35
30
25
20
15
10
7.5
5.0
2.0
2.5
3.0
3.5
4.0
LAYBARGE
DREDGE
MERGER POINT
~200m
①
②
③
④
SOUTH ARM PIPELINE ROUTE
LOWER FORESLOPE
FORESLOPE CREST
INTERTIDAL FLATS
E

OFFSHORE TIDAL FLATS SECTION

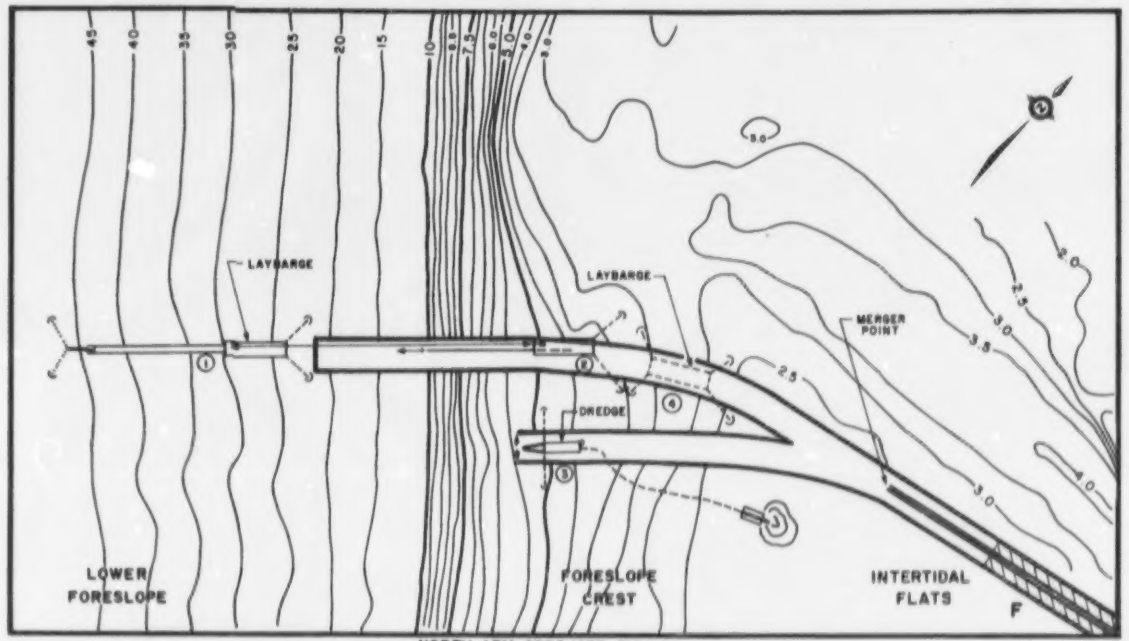
1) DREDGE CONTINUES BEYOND TRENCH MERGER POINT AND
EXCAVATES NORTH ARM TRENCH.
2) BACKFILLING CEASES 200m BEFORE MERGER POINT.
THEN DREDGED MATERIAL IS STOCKPILED.
3) PIPES ARE LAID TO MERGER POINT. THEN CAPPED
AND ENDS LOWERED INTO TRENCH.
4) NORTH ARM SHEAVE BLOCK IS POSITIONED BY LAYBARGE.

SCALE
0 50 100 200 300 m

PLATE 5-8

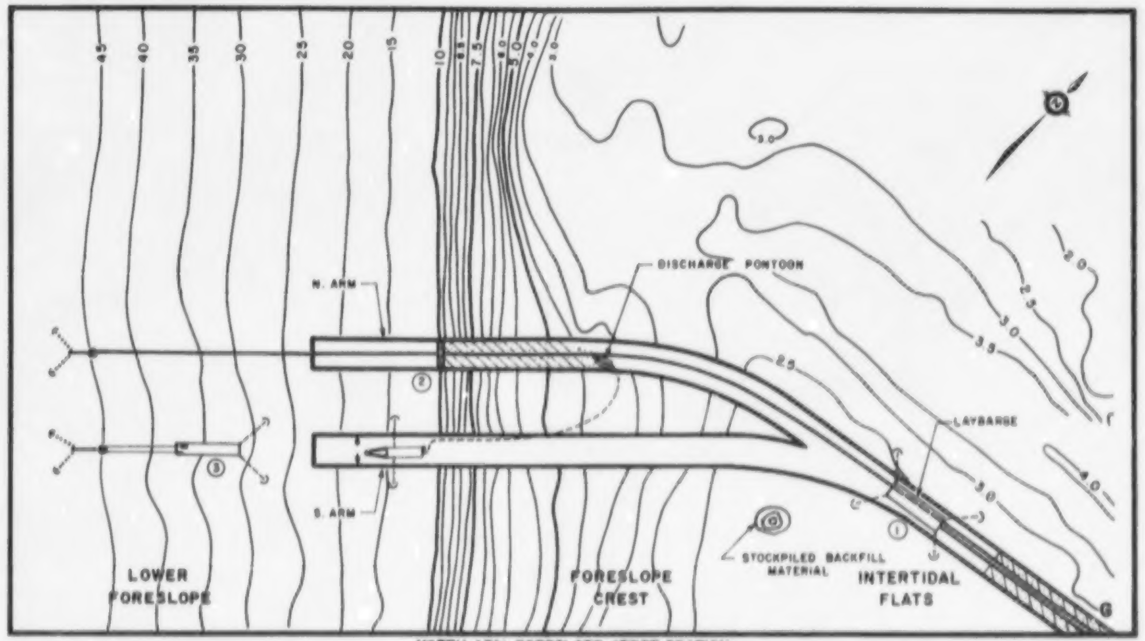
B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

SEAWARDS CONSTRUCTION
SEQUENCE OF MARINE OPERATIONS PART I


45
40
35
30
25
20
15
10
3.0
LAYBARGE
LAYBARGE
DREDGE
MERGER POINT
2.5
3.5
3.0
2.5
2.0
4.0
①
②
③
④
⑤
LOWER FORESLOPE
FORESLOPE CREST
INTERTIDAL FLATS
F

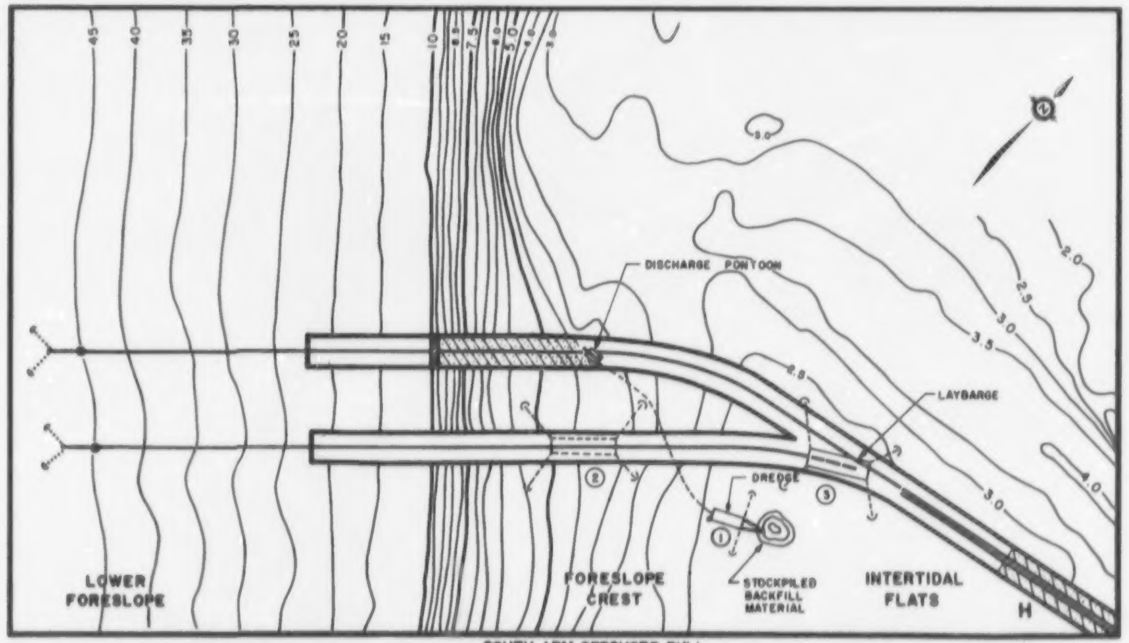
NORTH ARM OFFSHORE PULL

1) PULLING WIRES ARE LAID TO FORESLOPE CREST.
2) LAYBARGE IS ANCHORED AT FORESLOPE CREST AND PIPELINE PULLED OVER STERN UNTIL END REACHES SHEAVE BLOCK.
3) DREDGE EXCAVATES SOUTH ARM TRENCH.
4) NORTH ARM PIPELINE IS LAID TO MERGER POINT.


45
40
35
30
25
20
15
10
7.5
5.0
3.0
N. ARM
S. ARM
DISCHARGE PONTOON
LAYBARGE
2.5
3.5
3.0
2.5
2.0
4.0
①
②
③
STOCKPILED BACKFILL MATERIAL
LOWER FORESLOPE
FORESLOPE CREST
INTERTIDAL FLATS
G

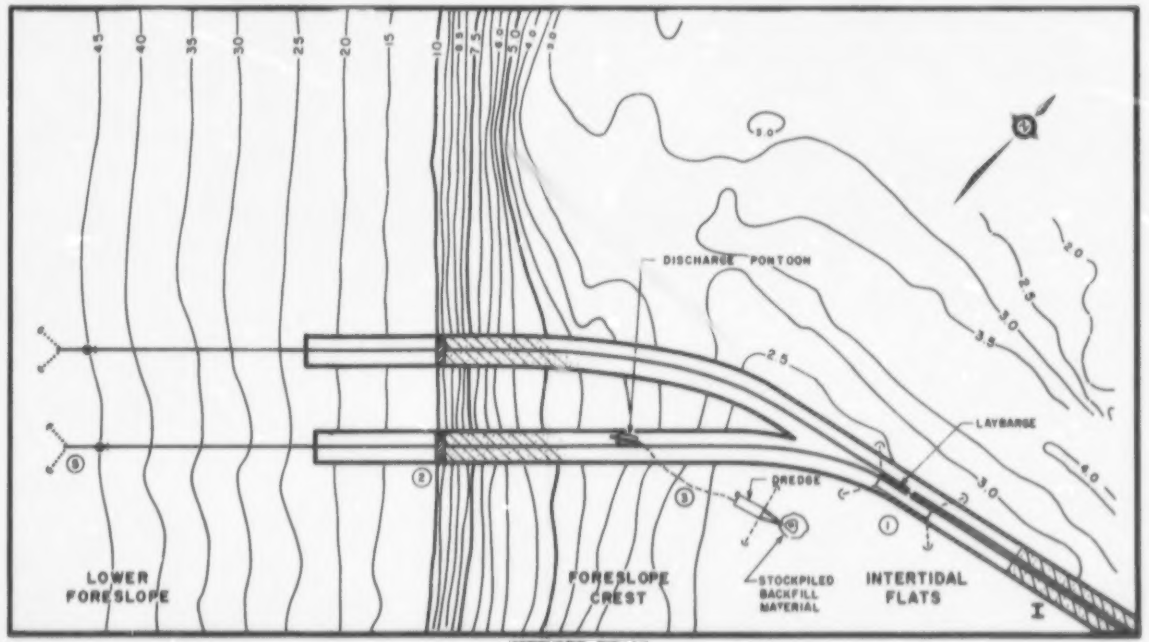
NORTH ARM FORESLOPE CREST SECTION

1) AT MERGER POINT PIPELINE IS CAPPED AND LOWERED INTO TRENCH.
2) SAND IS DUMPED FROM SCOWS ACROSS NORTH ARM TRENCH TO FORM A SEAL AND EXCAVATED MATERIAL FROM SOUTH ARM TRENCH IS DISCHARGED BEHIND IT.
3) SOUTH ARM SHEAVE BLOCK IS POSITIONED AND PULLING WIRES LAID TO FORESLOPE CREST.


45
40
35
30
25
20
15
10
7.5
5.0
3.0
DISCHARGE PONTOON
LAYBARGE
DREDGE
2.5
3.5
3.0
2.5
2.0
4.0
①
②
③
STOCKPILED BACKFILL MATERIAL
LOWER FORESLOPE
FORESLOPE CREST
INTERTIDAL FLATS
H

SOUTH ARM OFFSHORE PULL

1) BACKFILLING OF NORTH ARM TRENCH IS COMPLETED BY DREDGING STOCKPILED MATERIAL.
2) LAYBARGE IS ANCHORED AT FORESLOPE CREST AND THE PIPELINE IS PULLED OVER STERN UNTIL END REACHES SHEAVE BLOCK.
3) SOUTH ARM PIPELINE IS LAID TO MERGER POINT. PIPELINE IS CAPPED AND LOWERED INTO BOTTOM OF TRENCH.


45
40
35
30
25
20
15
10
7.5
5.0
3.0
DISCHARGE PONTOON
LAYBARGE
DREDGE
2.5
3.5
3.0
2.5
2.0
4.0
①
②
③
⑤
STOCKPILED BACKFILL MATERIAL
LOWER FORESLOPE
FORESLOPE CREST
INTERTIDAL FLATS
I

OFFSHORE TIE-IN

1) PIPELINES ARE TIED-IN.
2) SAND IS DUMPED FROM SCOWS ACROSS SOUTH ARM TRENCH TO TO FORM A SEAL.
3) BACKFILLING OF TRENCH IS COMPLETED WITH STOCKPILED MATERIAL AND MATERIAL DREDGED FROM FORESLOPE.
4) PIPELINES ARE HYDROSTATICALLY TESTED.
5) SHEAVE BLOCKS AND ANCHORS ARE RECOVERED AND MARINE EQUIPMENT IS DEMOBILISED.

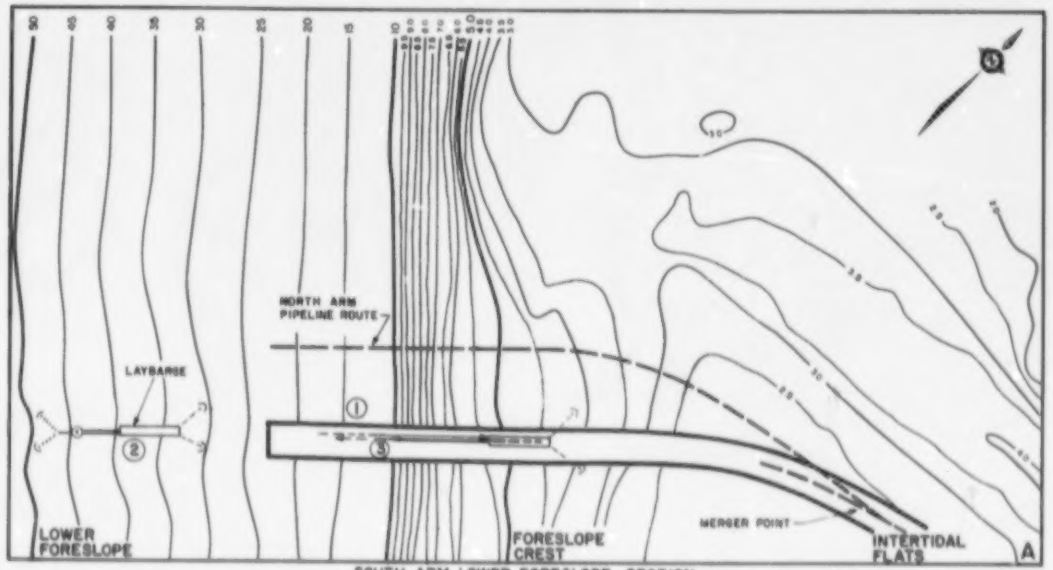
SCALE

0 50 100 200 300 m

PLATE 5-9

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

SEAWARDS CONSTRUCTION
SEQUENCE OF MARINE OPERATIONS PART II

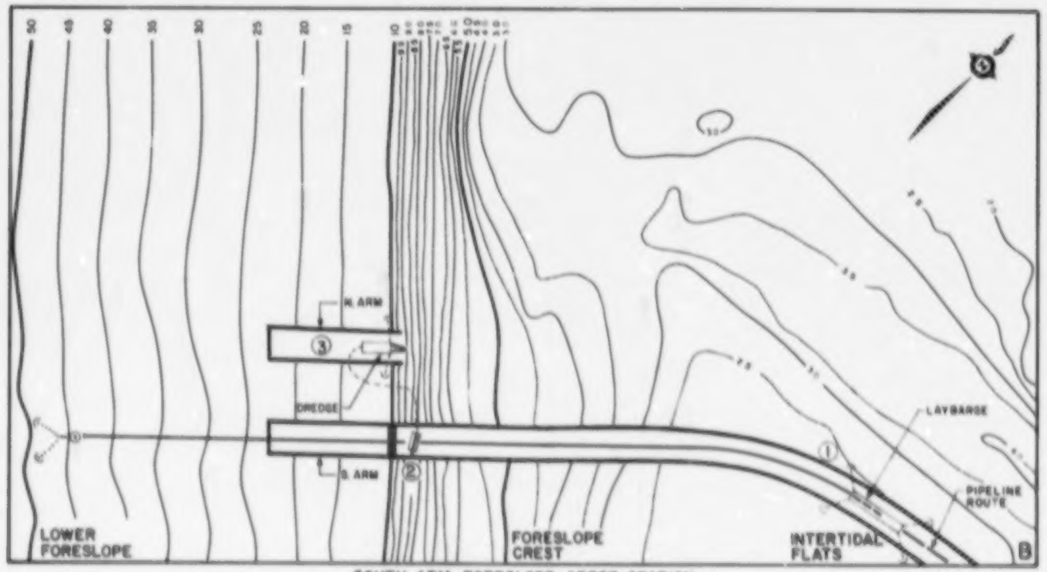

50
45
40
35
30
25
20
15
10
NORTH ARM PIPELINE ROUTE
LAYBARGE
①
②
③
LOWER FORESLOPE
FORESLOPE CREST
MERGER POINT
INTERTIDAL FLATS
A

SOUTH ARM LOWER FORESLOPE SECTION

1) DREDGE EXCAVATES SOUTH ARM TRENCH TO MERGER POINT. DREDGED MATERIAL DEPOSITED ON FORESLOPE.

2) SOUTH ARM SHEAVE BLOCK IS POSITIONED AND PULLING WIRES ARE LAID TO FORESLOPE CREST.

3) LAY BARGE IS ANCHORED AT FORESLOPE CREST AND PIPELINE PULLED OVER STERN UNTIL END REACHES SHEAVE BLOCK.

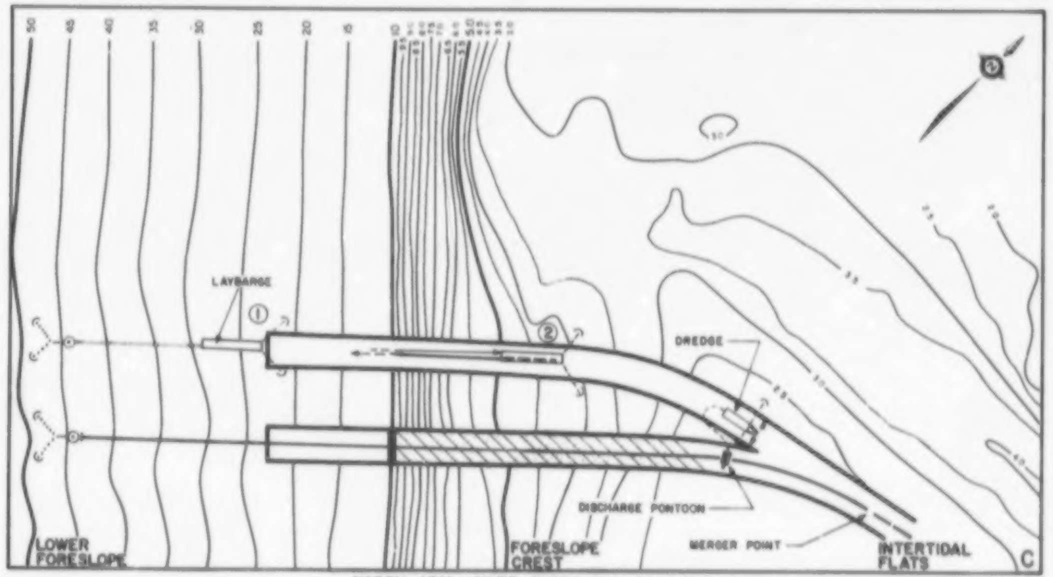

50
45
40
35
30
25
20
15
10
N. ARM
③
DREDGE
S. ARM
②
①
LAYBARGE
PIPELINE ROUTE
LOWER FORESLOPE
FORESLOPE CREST
INTERTIDAL FLATS
B

SOUTH ARM FORESLOPE CREST SECTION

1) SOUTH ARM PIPELINE IS LAID TO MERGER POINT, THEN CAPPED AND LOWERED INTO BOTTOM OF TRENCH.

2) SAND IS DUMPED FROM SCOWS ACROSS SOUTH ARM TO FORM A SEAL.

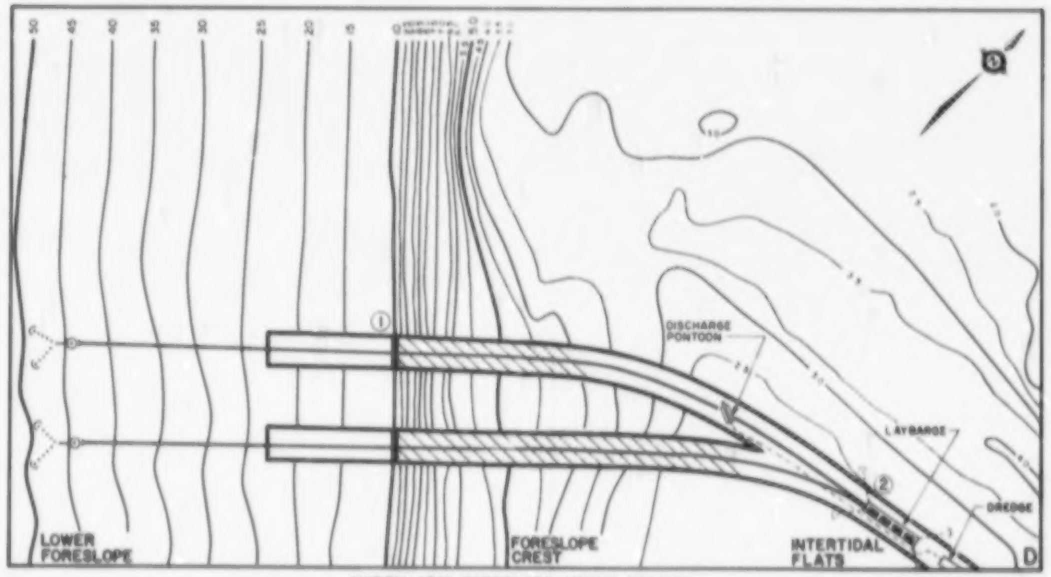
3) DREDGE EXCAVATES NORTH ARM TRENCH. DREDGED MATERIAL DISCHARGED INTO SOUTH ARM TRENCH.


50
45
40
35
30
25
20
15
10
LAYBARGE
①
②
DREDGE
DISCHARGE PONTOON
MERGER POINT
LOWER FORESLOPE
FORESLOPE CREST
INTERTIDAL FLATS
C

NORTH ARM LOWER FORESLOPE SECTION

1) NORTH ARM SHEAVE BLOCK IS POSITIONED AND PULLING WIRES ARE LAID TO FORESLOPE CREST.

2) LAYBARGE IS ANCHORED AT FORESLOPE CREST AND PIPELINE PULLED OVER STERN UNTIL END REACHES SHEAVE BLOCK.


50
45
40
35
30
25
20
15
10
①
DISCHARGE PONTOON
LAYBARGE
②
DREDGE
LOWER FORESLOPE
FORESLOPE CREST
INTERTIDAL FLATS
D

NORTH ARM FORESLOPE CREST SECTION

1) SAND IS DUMPED FROM SCOWS ACROSS NORTH ARM TO FORM A SEAL.

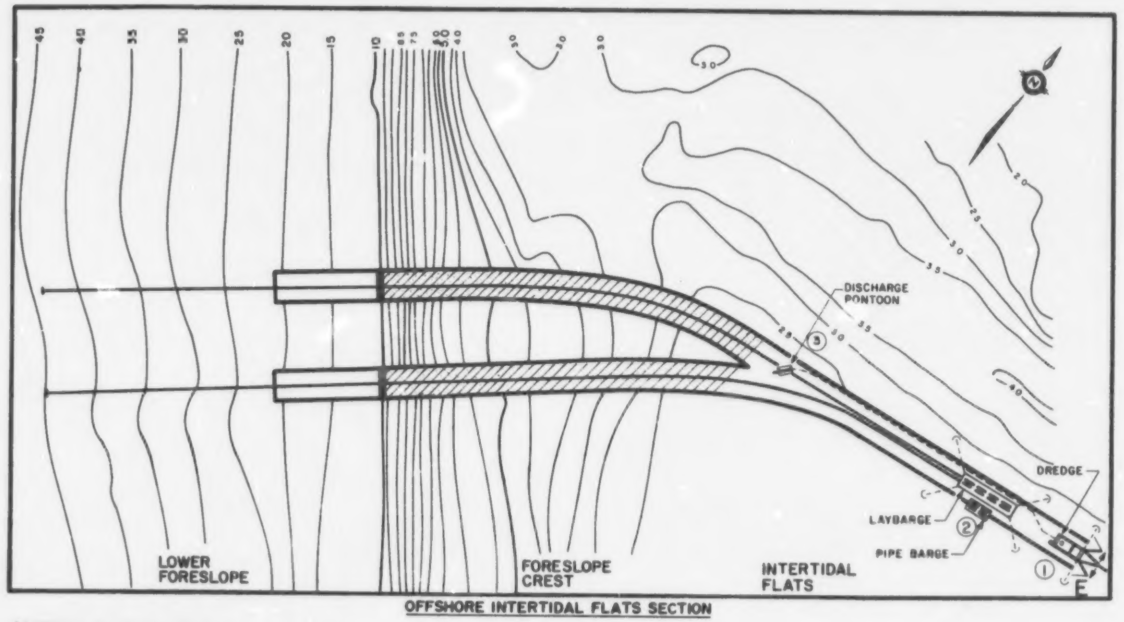
2) NORTH ARM PIPELINE IS LAID TO MERGER POINT. SOUTH ARM PIPELINE IS RAISED AND BOTH LINES ARE PREPARED FOR LAYING ACROSS INTERTIDAL FLATS.

SCALE
0 50 100 200 300m

PLATE 5-10

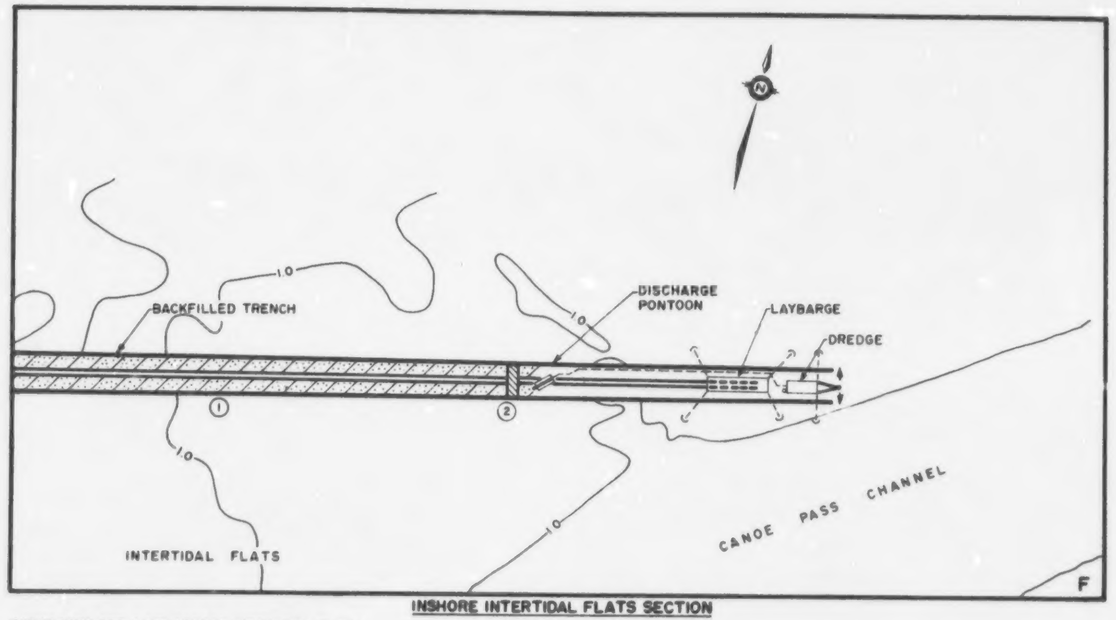
B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

LANDWARDS CONSTRUCTION
SEQUENCE OF MARINE OPERATIONS PART I


45
40
35
30
25
20
15
10
DISCHARGE PONTOON
DREDGE
LAYBARGE
PIPE BARGE
LOWER FORESLOPE
FORESLOPE CREST
INTERTIDAL FLATS
①
②
③
E

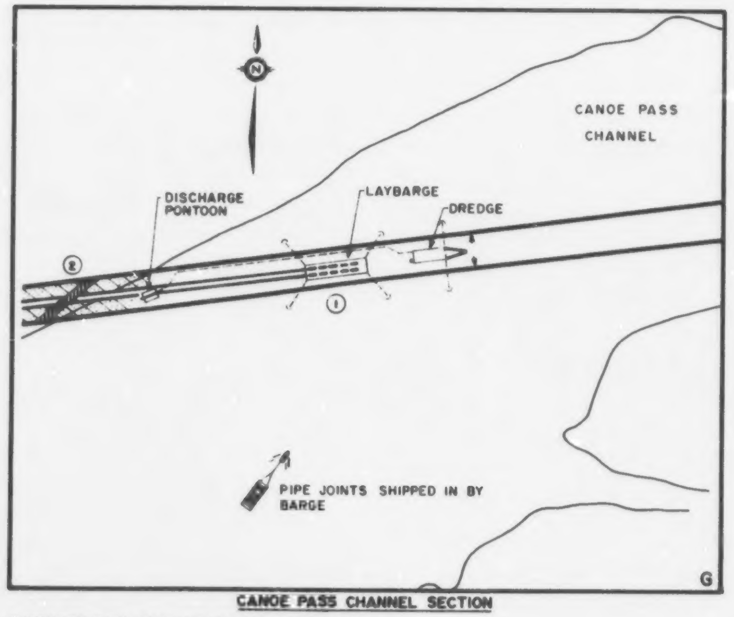
OFFSHORE INTERTIDAL FLATS SECTION

1) DREDGE EXCAVATES TRENCH.
2) LAYBARGE FOLLOWS LAYING TWO PIPELINES.
3) DISCHARGE PONTOON FOLLOWS BEHIND LAYBARGE BACKFILLING THE TRENCH.


N
BACKFILLED TRENCH
DISCHARGE PONTOON
LAYBARGE
DREDGE
1.0
①
②
INTERTIDAL FLATS
CANOE PASS CHANNEL
F

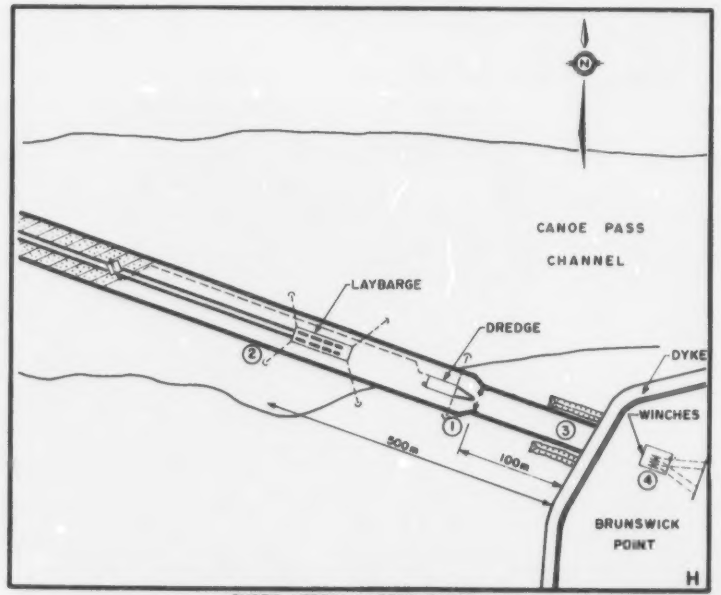
INSHORE INTERTIDAL FLATS SECTION

1) PIPELINES ARE LAID ACROSS INTERTIDAL FLATS.
2) PRIOR TO BREAKING THROUGH CANOE PASS CHANNEL BANK. SAND IS DUMPED FROM SCOWS ACROSS CONSTRUCTION TRENCH TO SEAL IT.


N
CANOE PASS CHANNEL
DISCHARGE PONTOON
LAYBARGE
DREDGE
①
②
PIPE JOINTS SHIPPED IN BY BARGE
G

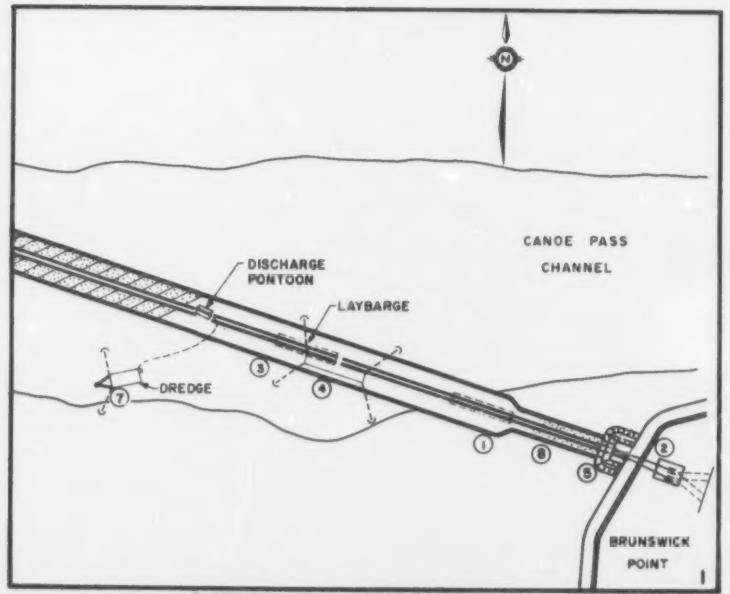
CANOE PASS CHANNEL SECTION

1) CONSTRUCTION TRAIN MOVES INTO CANOE PASS CHANNEL.
2) SAND IS DUMPED FROM SCOWS ACROSS TRENCH TO FORM SECOND SEAL.


N
CANOE PASS CHANNEL
LAYBARGE
DREDGE
DYKE
WINCHES
500m
100m
①
②
③
④
BRUNSWICK POINT
H

SHORE APPROACH PREPARATION

1) TRENCH IS EXCAVATED TO 100m FROM DYKE.
2) PIPELINES ARE LAID TO WITHIN 500m OF DYKE. THEN CAPPED AND LOWERED INTO TRENCH.
3) SHORE APPROACH TRENCH IS EXCAVATED. MATERIAL IS STOCKPILED EITHER SIDE OF TRENCH.
4) SHORE PULL WINCHES ARE SET UP.


N
CANOE PASS CHANNEL
DISCHARGE PONTOON
LAYBARGE
DREDGE
①
②
③
④
⑤
⑦
⑧
BRUNSWICK POINT
I

SHORE PULL FROM LAYBARGE AND TIE-IN

1) LAYBARGE SETS UP 150m OFFSHORE.
2) PIPESTRINGS ARE PULLED ASHORE.
3) LAYBARGE MOVES OFFSHORE AND PIPES ARE LAID TO ENDS OF PIPELINES COMPLETED EARLIER.
4) PIPELINES ARE TIED-IN.
5) COFFERDAM IS CONSTRUCTED AT DYKE (SEE PLATE 5-21) SHORE PULL WINCHES REMOVED AND PIPELINES LAID INSHORE.
6) PIPELINES ARE HYDROSTATICALLY TESTED.
7) TRENCH IS BACKFILLED BY DREDGING SAND FROM LOCAL SAND BANKS.
8) DYKE AND SHORE APPROACH TRENCH ARE BACKFILLED AND COFFERDAM REMOVED.
9) SHEAVE BLOCKS AND ANCHORS ARE RECOVERED AND MARINE EQUIPMENT IS DEMOBILIZED.

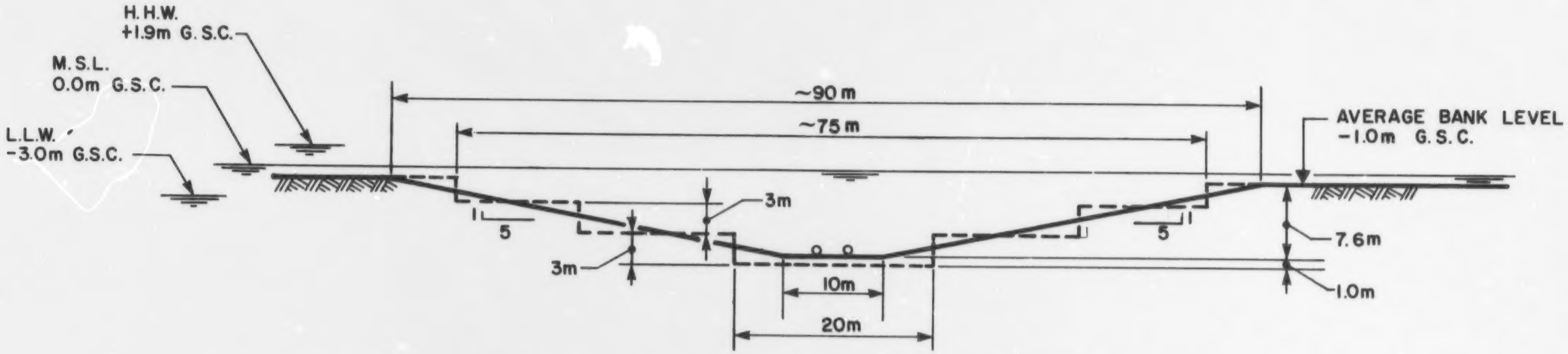
SCALE
0 50 100 200 300 m

PLATE 5-11

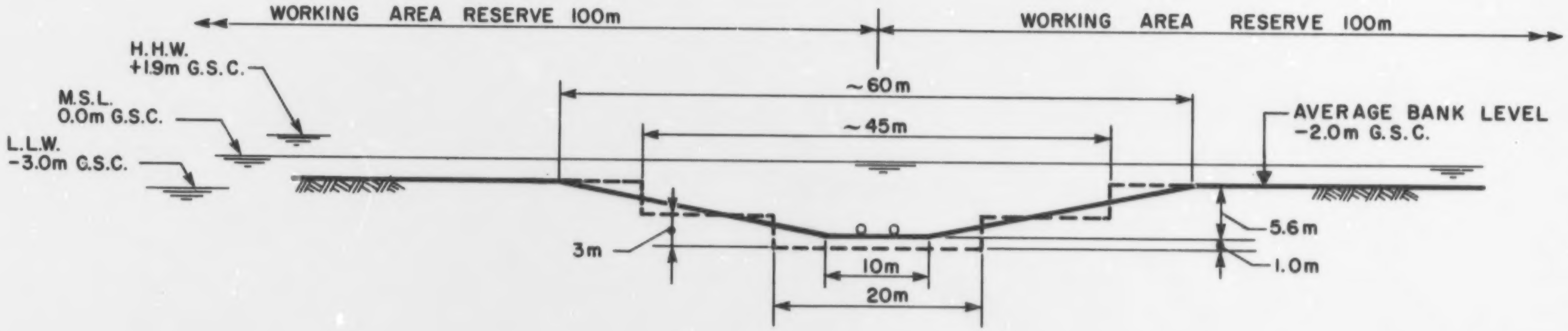
B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

LANDWARDS CONSTRUCTION
SEQUENCE OF MARINE OPERATIONS PART II

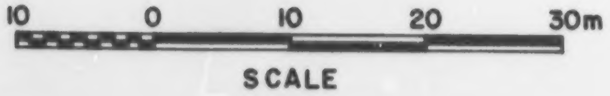
MONENCO PIPELINE CONSULTANTS LTD.


H.H.W.
+1.9m G.S.C.
M.S.L.
0.0m G.S.C.
L.L.W.
-3.0m G.S.C.
~90 m
~75 m
AVERAGE BANK LEVEL
-1.0m G.S.C.
3m
5
5
3m
7.6m
10m
1.0m
20m

TRENCH CROSS SECTION ACROSS INTERTIDAL FLATS
CHAINAGE 2 840.00 – 6 420.00


WORKING AREA RESERVE 100m
WORKING AREA RESERVE 100m
H.H.W.
+1.9m G.S.C.
M.S.L.
0.0m G.S.C.
L.L.W.
-3.0m G.S.C.
~60m
~45m
AVERAGE BANK LEVEL
-2.0m G.S.C.
3m
5.6m
10m
1.0m
20m

TRENCH CROSS SECTION ACROSS INTERTIDAL FLATS
CHAINAGE 6 420.00 – 8 550.00


10
0
10
20
30m
SCALE

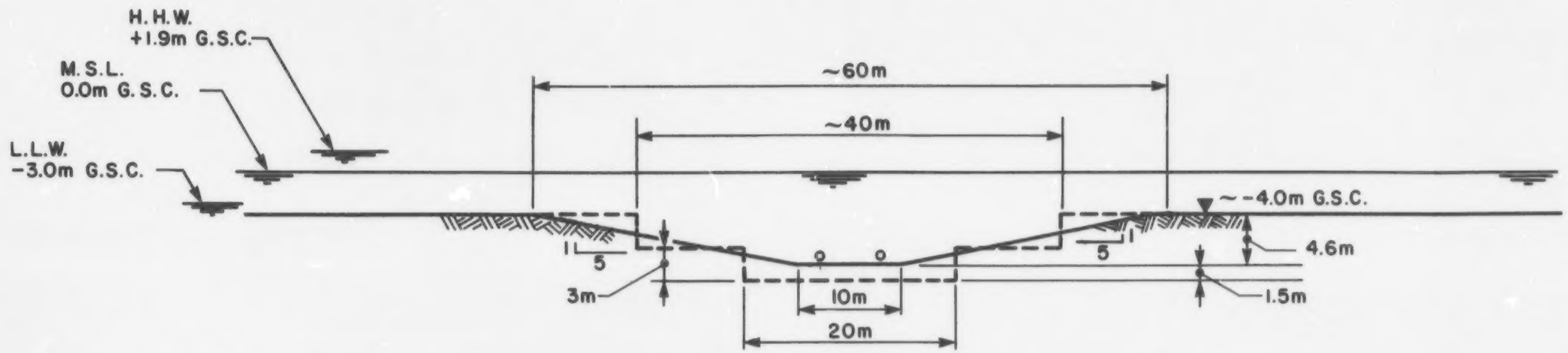
NOTES

SOLID LINE DENOTES ASSUMED TRENCH PROFILE PRIOR TO PIPELAYING.

DASHED LINE DENOTES DREDGED PROFILE.

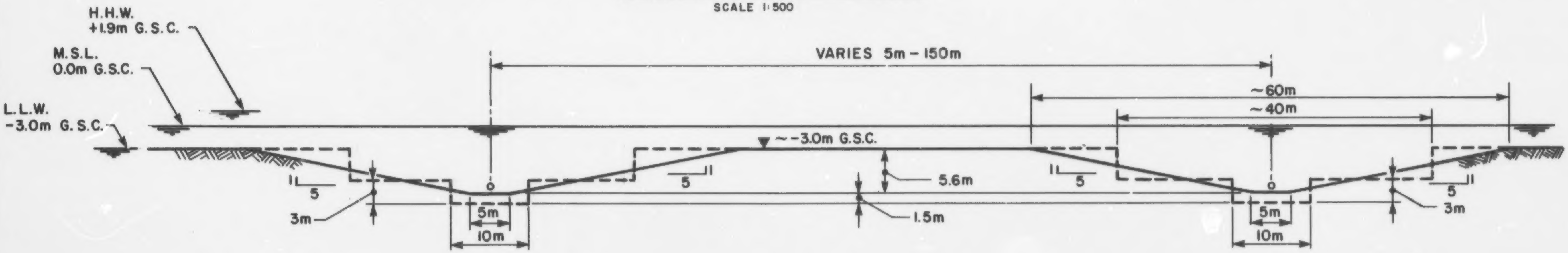
PLATE 5-12
B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT.

TYPICAL TRENCH CROSS SECTIONS ACROSS INTERTIDAL FLATS CHAINAGE 2 840.00-8 550.00 METRES


H.H.W.
+1.9m G.S.C.
M.S.L.
0.0m G.S.C.
L.L.W.
-3.0m G.S.C.
~60m
~40m
~-4.0m G.S.C.
1
5
5
1
4.6m
1.5m
3m
10m
20m

TRENCH CROSS SECTION WITHIN CANOE PASS
CHAINAGE 100.00 - 2 840.00

SCALE 1:500


H.H.W.
+1.9m G.S.C.
M.S.L.
0.0m G.S.C.
L.L.W.
-3.0m G.S.C.
VARIES 5m - 150m
~60m
~40m
~-3.0m G.S.C.
1
5
5
1
5.6m
1.5m
1
5
5
1
3m
3m
5m
10m
5m
10m

TRENCH CROSS SECTION ACROSS FORESLOPE
CHAINAGE 8 550.00-9 475.00

SCALE 1:500

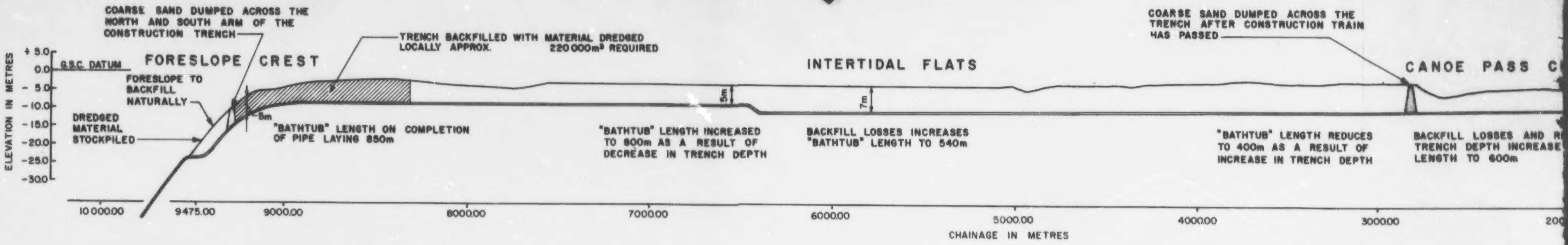
NOTES

SOLID LINE DENOTES ASSUMED TRENCH PROFILE PRIOR TO PIPELAYING

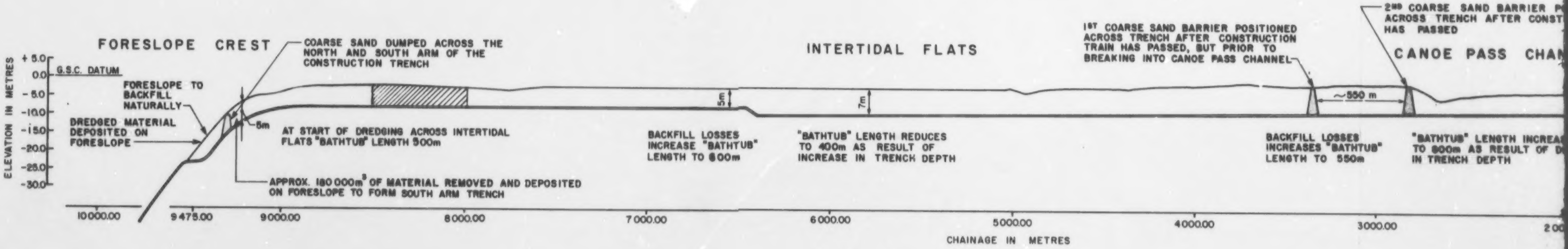
DASHED LINE DENOTES DREDGED PROFILE.

PLATE 5-13
B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT
TRENCH CROSS SECTIONS
WITHIN CANOE PASS AND ACROSS FORESLOPE

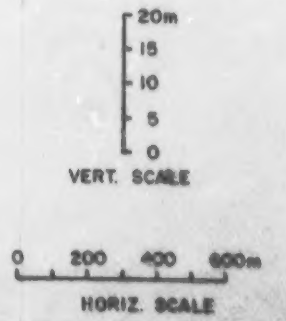
MONENCO PIPELINE CONSULTANTS LTD.

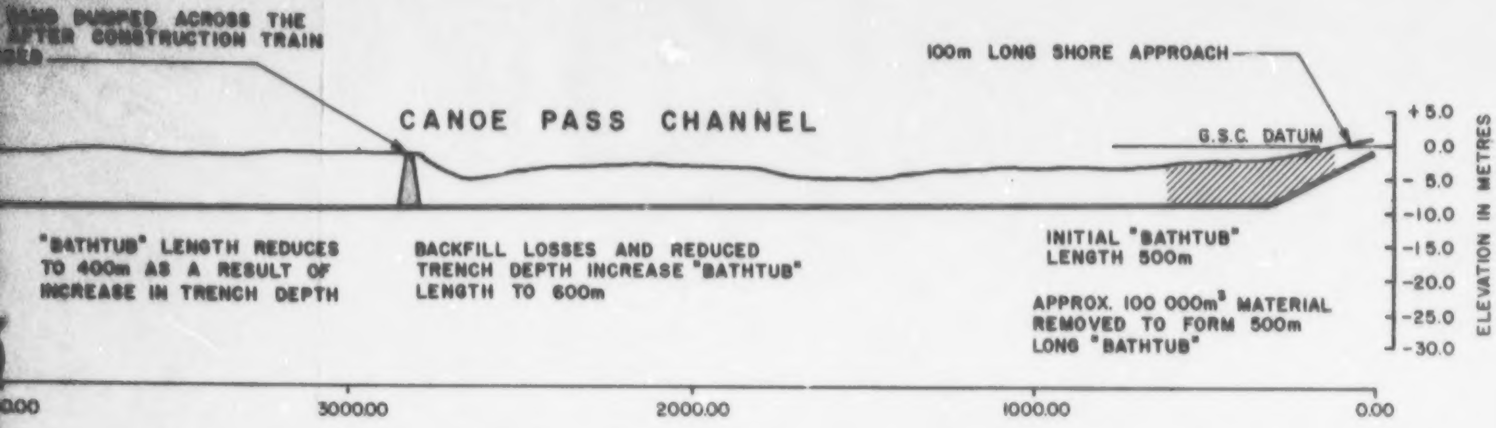

COARSE SAND DUMPED ACROSS THE NORTH AND SOUTH ARM OF THE CONSTRUCTION TRENCH
TRENCH BACKFILLED WITH MATERIAL DREDGED LOCALLY APPROX. 220 000m³ REQUIRED
COARSE SAND DUMPED ACROSS THE TRENCH AFTER CONSTRUCTION TRAIN HAS PASSED
ELEVATION IN METRES
+5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
G.S.C. DATUM
FORESLOPE CREST
INTERTIDAL FLATS
CANOE PASS
FORESLOPE TO BACKFILL NATURALLY
DREDGED MATERIAL STOCKPILED
5m
5m
7m
"BATHTUB" LENGTH ON COMPLETION OF PIPE LAYING 850m
"BATHTUB" LENGTH INCREASED TO 800m AS A RESULT OF DECREASE IN TRENCH DEPTH
BACKFILL LOSSES INCREASES "BATHTUB" LENGTH TO 540m
"BATHTUB" LENGTH REDUCES TO 400m AS A RESULT OF INCREASE IN TRENCH DEPTH
BACKFILL LOSSES AND
TRENCH DEPTH INCREASE
LENGTH TO 600m
10 000.00
9475.00
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
CHAINAGE IN METRES

SEAWARDS CONSTRUCTION

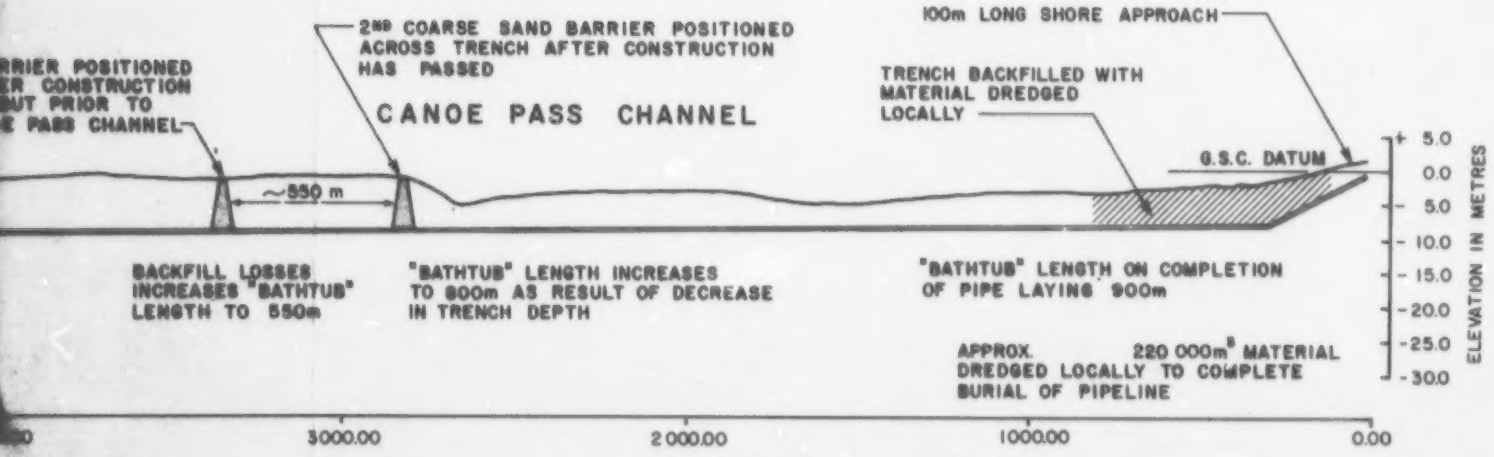

FORESLOPE CREST
COARSE SAND DUMPED ACROSS THE NORTH AND SOUTH ARM OF THE CONSTRUCTION TRENCH
INTERTIDAL FLATS
1ST COARSE SAND BARRIER POSITIONED ACROSS TRENCH AFTER CONSTRUCTION TRAIN HAS PASSED, BUT PRIOR TO BREAKING INTO CANOE PASS CHANNEL
2ND COARSE SAND BARRIER
ACROSS TRENCH AFTER CONST
HAS PASSED
CANOE PASS CHAN
ELEVATION IN METRES
+5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
G.S.C. DATUM
FORESLOPE TO BACKFILL NATURALLY
DREDGED MATERIAL DEPOSITED ON FORESLOPE
5m
5m
7m
~550 m
AT START OF DREDGING ACROSS INTERTIDAL FLATS "BATHTUB" LENGTH 500m
APPROX. 180 000m³ OF MATERIAL REMOVED AND DEPOSITED ON FORESLOPE TO FORM SOUTH ARM TRENCH
BACKFILL LOSSES INCREASE "BATHTUB" LENGTH TO 600m
"BATHTUB" LENGTH REDUCES TO 400m AS RESULT OF INCREASE IN TRENCH DEPTH
BACKFILL LOSSES INCREASES "BATHTUB" LENGTH TO 550m
"BATHTUB" LENGTH INCREA
TO 800m AS RESULT OF D
IN TRENCH DEPTH
10000.00
9475.00
9000.00
8000.00
7000.00
6000.00
5000.00
4000.00
3000.00
CHAINAGE IN METRES

LANDWARDS CONSTRUCTION

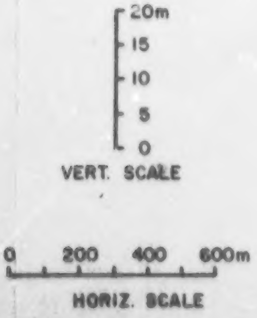

20m
15
10
5
0
VERT. SCALE
0
200
400
600m
HORIZ. SCALE



SAND DUMPED ACROSS THE
AFTER CONSTRUCTION TRAIN
SED
100m LONG SHORE APPROACH
CANOE PASS CHANNEL
G.S.C. DATUM
"BATHTUB" LENGTH REDUCES TO 400m AS A RESULT OF INCREASE IN TRENCH DEPTH
BACKFILL LOSSES AND REDUCED TRENCH DEPTH INCREASE "BATHTUB" LENGTH TO 600m
INITIAL "BATHTUB" LENGTH 500m
APPROX. 100 000m³ MATERIAL REMOVED TO FORM 500m LONG "BATHTUB"
+5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
ELEVATION IN METRES
000
3000.00
2000.00
1000.00
0.00



2ND COARSE SAND BARRIER POSITIONED ACROSS TRENCH AFTER CONSTRUCTION HAS PASSED
RRIER POSITIONED
ER CONSTRUCTION
BUT PRIOR TO
E PASS CHANNEL
100m LONG SHORE APPROACH
TRENCH BACKFILLED WITH MATERIAL DREDGED LOCALLY
CANOE PASS CHANNEL
G.S.C. DATUM
~550 m
BACKFILL LOSSES INCREASES "BATHTUB" LENGTH TO 550m
"BATHTUB" LENGTH INCREASES TO 800m AS RESULT OF DECREASE IN TRENCH DEPTH
"BATHTUB" LENGTH ON COMPLETION OF PIPE LAYING 900m
APPROX. 220 000m³ MATERIAL DREDGED LOCALLY TO COMPLETE BURIAL OF PIPELINE
+5.0
0.0
5.0
10.0
15.0
20.0
25.0
30.0
ELEVATION IN METRES
3000.00
2000.00
1000.00
0.00



20m
15
10
5
0
VERT. SCALE
0
200
400
600m
HORIZ. SCALE

PLATE 5-14

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

EXCAVATION AND BACKFILL MATERIAL BALANCE

MONENCO PIPELINE CONSULTANTS LTD.

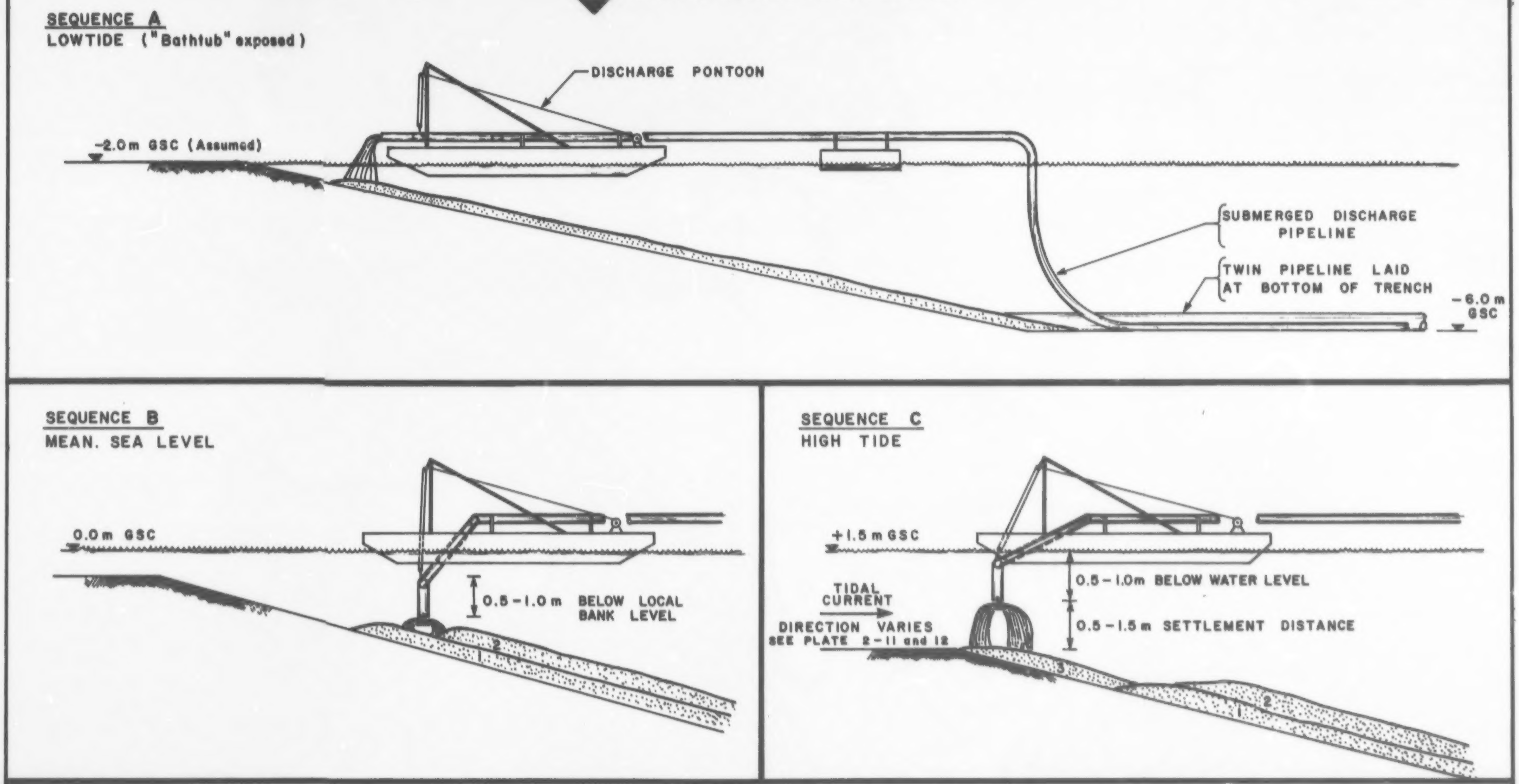

SEQUENCE A
LOWTIDE ("Bathtub" exposed)
DISCHARGE PONTOON
-2.0 m GSC (Assumed)
SUBMERGED DISCHARGE PIPELINE
TWIN PIPELINE LAID AT BOTTOM OF TRENCH
-6.0 m GSC
SEQUENCE B
MEAN. SEA LEVEL
0.0 m GSC
0.5 - 1.0 m BELOW LOCAL BANK LEVEL
1
2
SEQUENCE C
HIGH TIDE
+1.5 m GSC
0.5 - 1.0 m BELOW WATER LEVEL
0.5 - 1.5 m SETTLEMENT DISTANCE
TIDAL CURRENT
DIRECTION VARIES SEE PLATE 2-11 and 12
3
1
2

PLATE 5-15

B.C. HYDRO AND POWER AUTHORITY

VANCOUVER ISLAND GAS PIPELINE PROJECT

OPERATION OF DISCHARGE PONTOON

INTERTIDAL FLATS

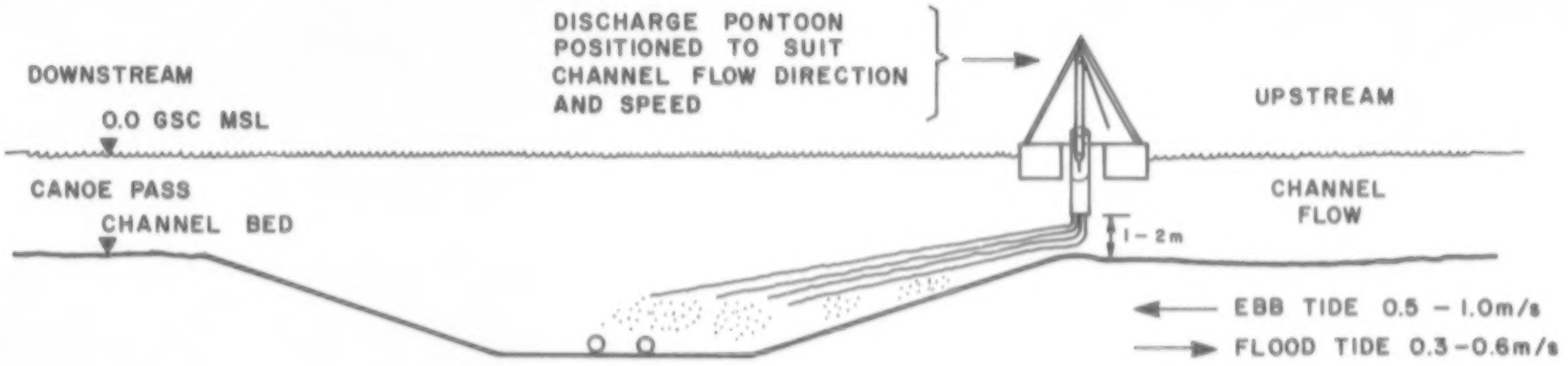
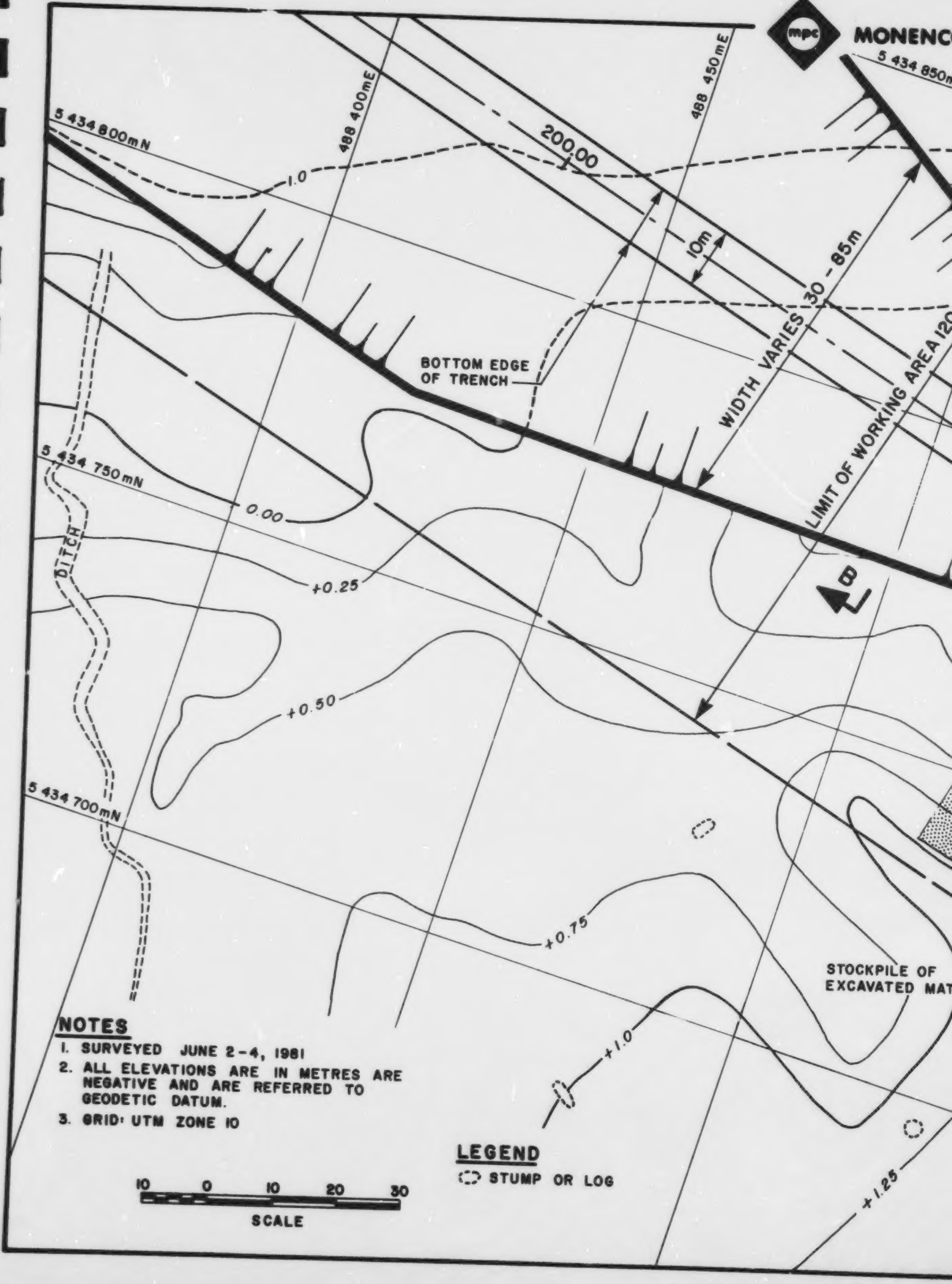

DISCHARGE PONTOON
POSITIONED TO SUIT
CHANNEL FLOW DIRECTION
AND SPEED
DOWNSTREAM
0.0 GSC MSL
UPSTREAM
CANOE PASS
CHANNEL BED
CHANNEL
FLOW
1 - 2m
EBB TIDE 0.5 - 1.0m/s
FLOOD TIDE 0.3-0.6m/s

PLATE 5-16

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

OPERATION OF DISCHARGE PONTOON CANOE PASS CHANNEL


MONENC
5 434 850m
488 400mE
488 450mE
5 434 800mN
5 434 750mN
5 434 700mN
200.00
10m
WIDTH VARIES 30 - 85m
LIMIT OF WORKING AREA 120
BOTTOM EDGE OF TRENCH
DITCH
-1.0
0.00
+0.25
+0.50
+0.75
+1.0
+1.25
B
STOCKPILE OF EXCAVATED MAT

NOTES

1. SURVEYED JUNE 2-4, 1981
2. ALL ELEVATIONS ARE IN METRES ARE NEGATIVE AND ARE REFERRED TO GEODETIC DATUM.
3. GRID: UTM ZONE 10

LEGEND

⬭ STUMP OR LOG

10 0 10 20 30

SCALE

PIPELINE CONSULTANTS LTD.

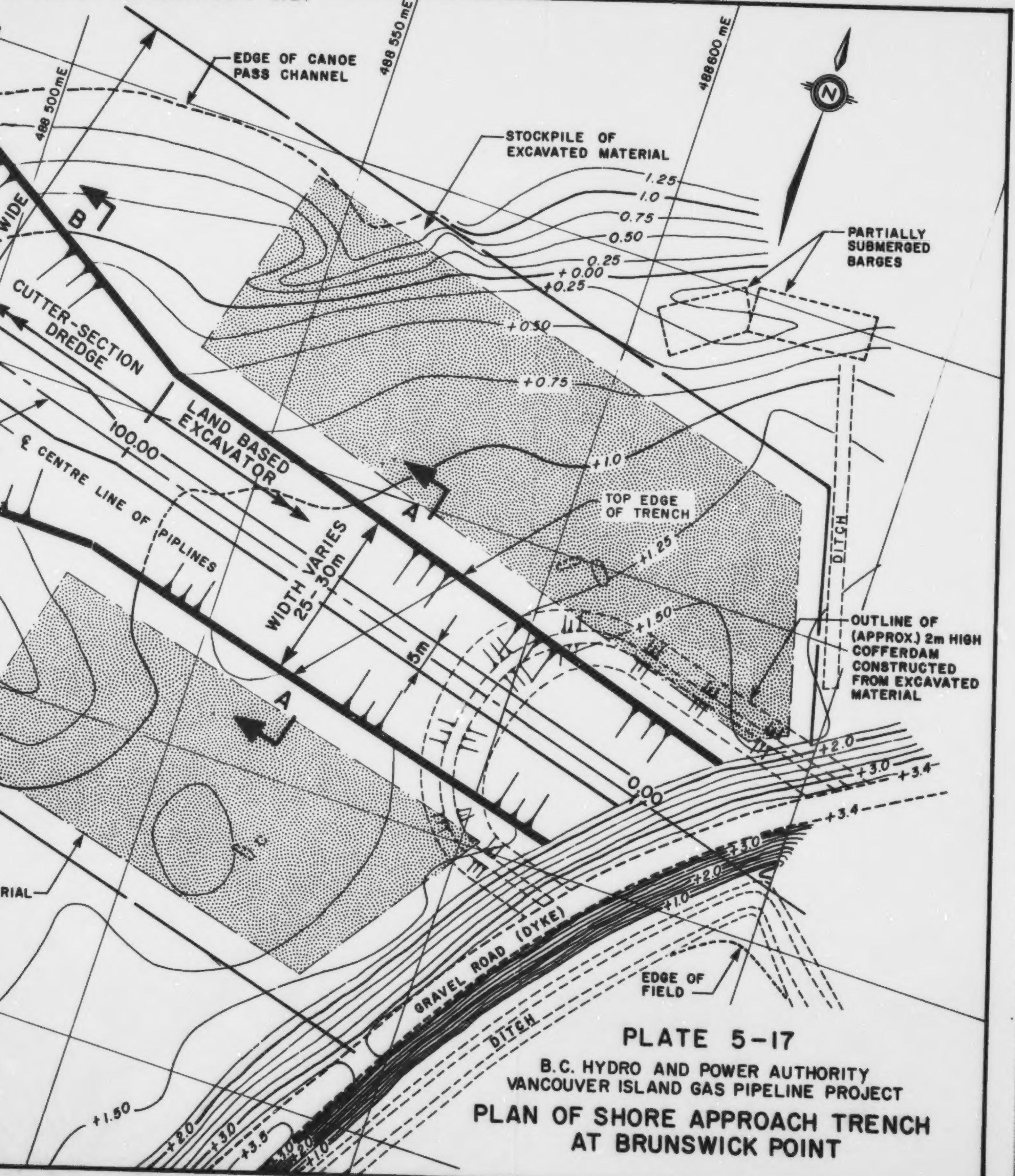
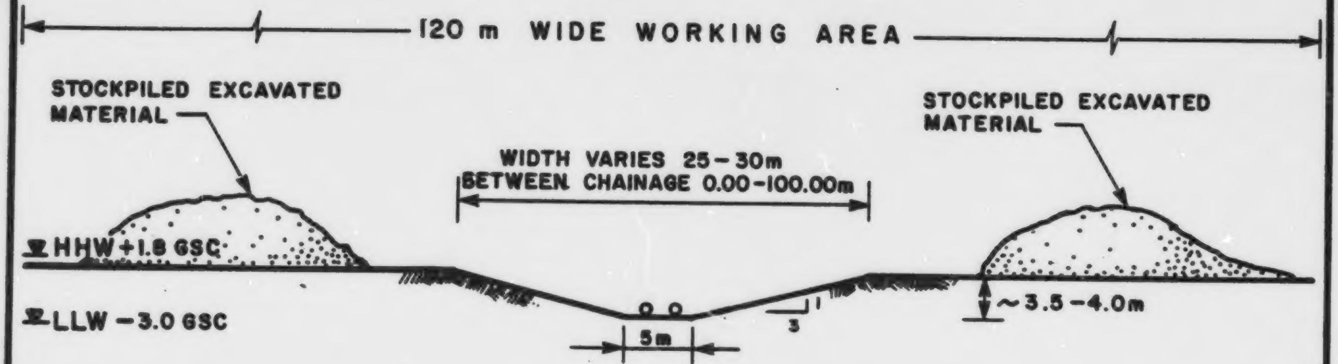

EDGE OF CANOE PASS CHANNEL
488 500mE
488 550 mE
488600 mE
STOCKPILE OF EXCAVATED MATERIAL
1.25
1.0
0.75
0.50
0.25
+ 0.00
+0.25
+0.50
+0.75
+1.0
+1.25
+1.50
WIDE
B
CUTTER-SECTION DREDGE
LAND BASED EXCAVATOR
100.00
℄ CENTRE LINE OF PIPLINES
A
WIDTH VARIES 25 - 30m
5m
TOP EDGE OF TRENCH
PARTIALLY SUBMERGED BARGES
DITCH
OUTLINE OF (APPROX.) 2m HIGH COFFERDAM CONSTRUCTED FROM EXCAVATED MATERIAL
0.00
+2.0
+3.0
+3.4
+3.4
+3.0
+2.0
+1.0
RIAL
GRAVEL ROAD (DYKE)
EDGE OF FIELD
DITCH
+1.50
+2.0
+3.0
+3.5
3.0
2.0
+1.0

PLATE 5-17

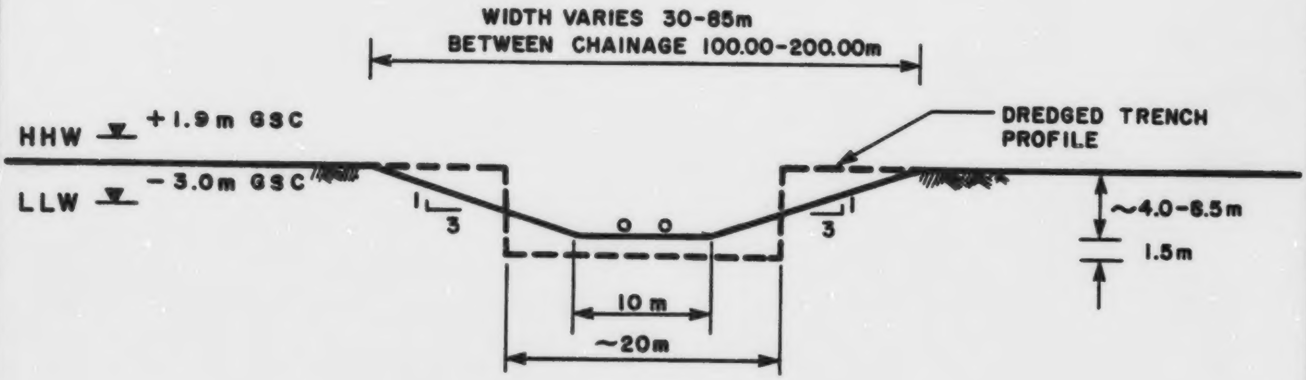
B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

PLAN OF SHORE APPROACH TRENCH AT BRUNSWICK POINT

MONENCO PIPELINE CONSULTANTS LTD.


120 m WIDE WORKING AREA
STOCKPILED EXCAVATED MATERIAL
STOCKPILED EXCAVATED MATERIAL
WIDTH VARIES 25 - 30m
BETWEEN CHAINAGE 0.00-100.00m
HHW +1.8 GSC
LLW -3.0 GSC
5m
1
3
~3.5 -4.0m

SECTION A (PLATE 5-17)
CHAINAGE 50.00


WIDTH VARIES 30-85m
BETWEEN CHAINAGE 100.00-200.00m
DREDGED TRENCH PROFILE
HHW +1.9m GSC
LLW -3.0m GSC
1
3
3
1
~4.0-8.5m
1.5m
10 m
~20m

SECTION B (PLATE 5-17)
CHAINAGE 125.00

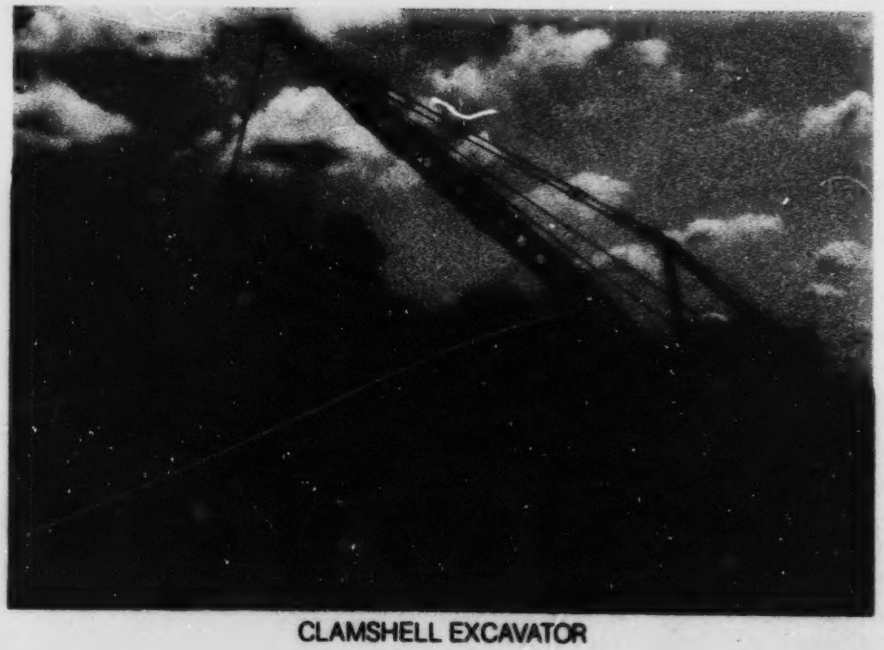
PLATE 5-18

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

TYPICAL SHORE APPROACH TRENCH CROSS SECTIONS

SCALE 1 : 500 m.

BACK-HOE EXCAVATOR



CLAMSHELL EXCAVATOR

PLATE 5-19

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

MONENCO PIPELINE CONSULTANTS LTD.

LAND BASED EXCAVATORS

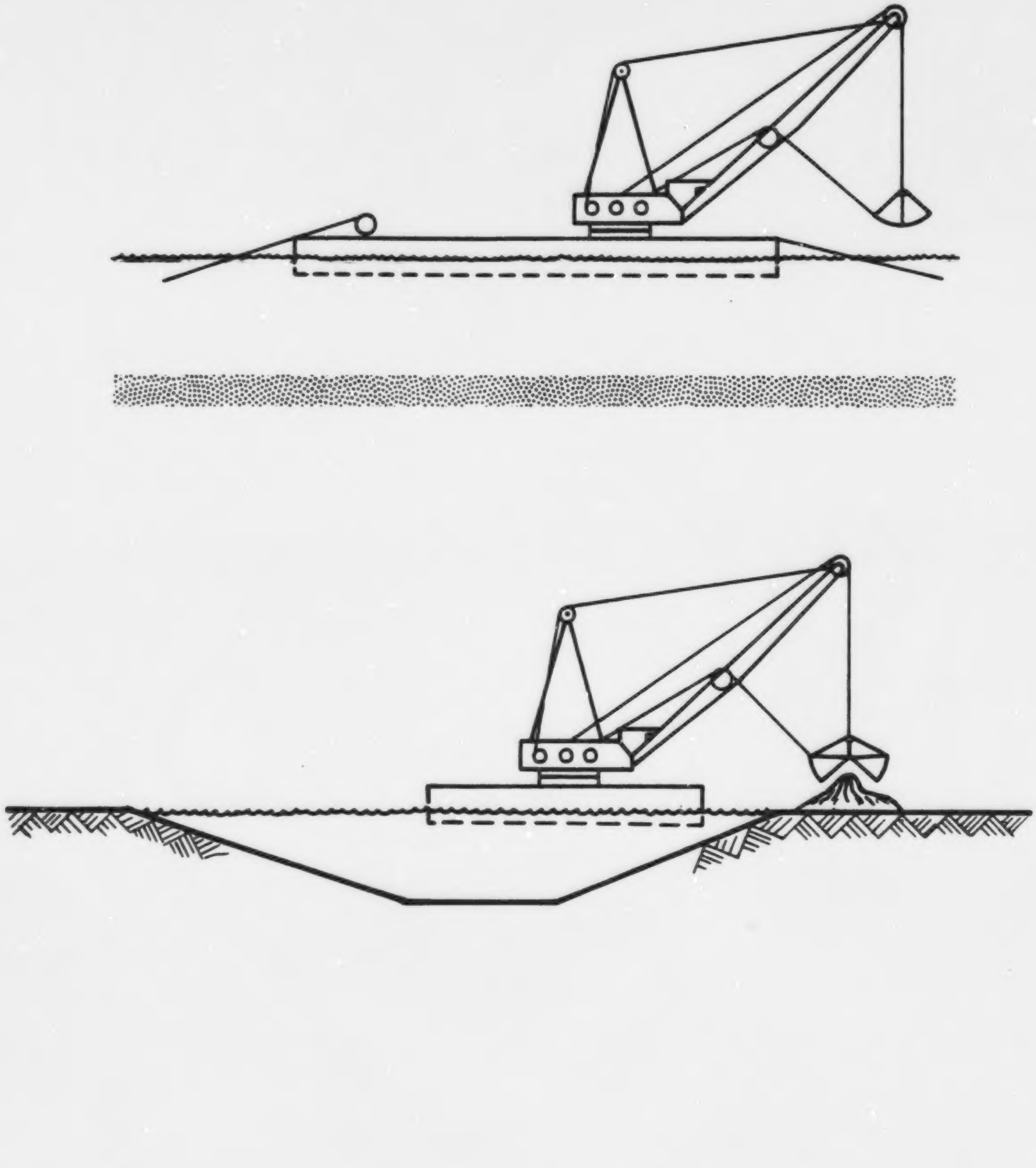
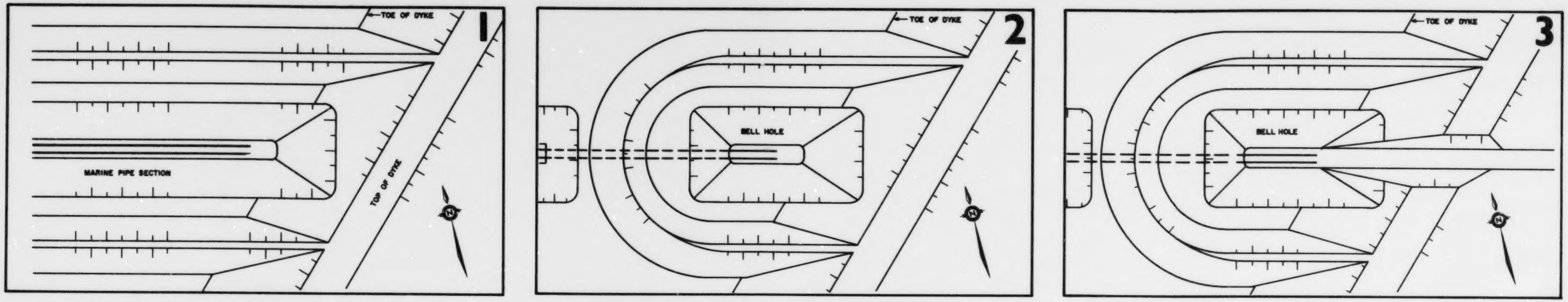


PLATE 5-20

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

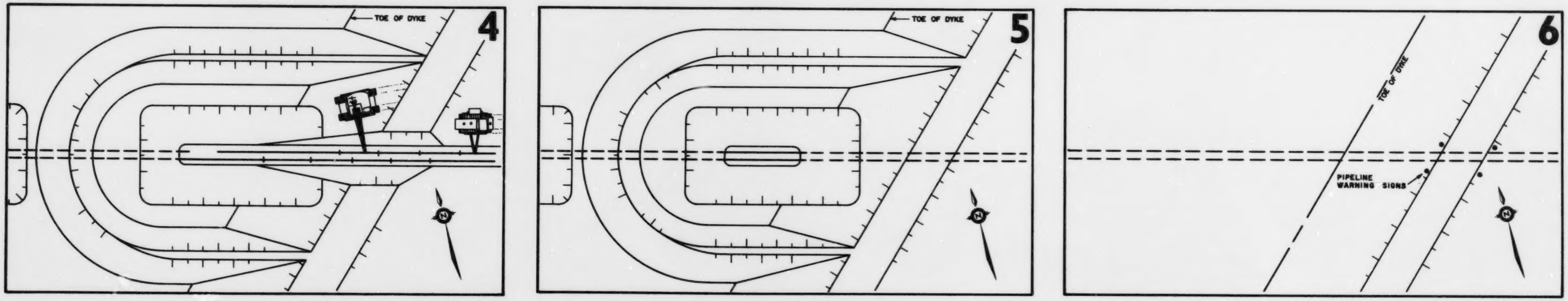
CLAMSHELL GRAB DREDGE


TOE OF DYKE
1
MARINE PIPE SECTION
TOP OF DYKE
N
TOE OF DYKE
2
BELL HOLE
N
TOE OF DYKE
3
BELL HOLE
N

A 5m WIDE TRENCH IS EXCAVATED UP TO THE TOE OF DYKE. THE MARINE PIPES ARE PULLED ASHORE FROM THE LAYBARGE.

A COFFER DAM IS CONSTRUCTED TO PREVENT THE SEA WATER ENTERING THE TRENCH DURING THE CUTTING THROUGH OF THE DYKE AND DURING THE HYDROSTATIC TEST.

TRENCH FOR THE LAND LINE IS CUT THROUGH THE DYKE EXTENDING INTO THE BELLHOLE.

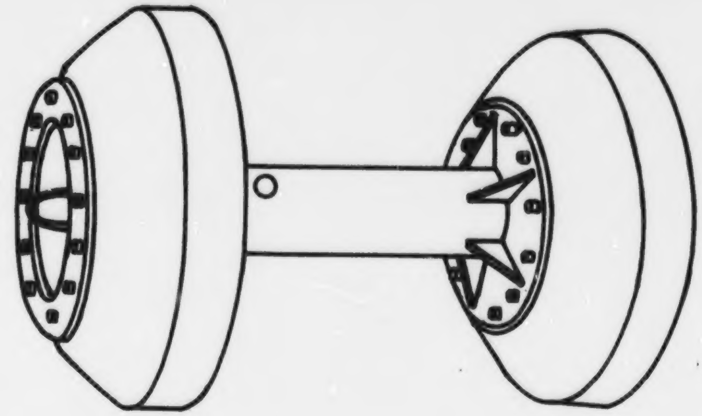

TOE OF DYKE
4
N
TOE OF DYKE
5
N
TOE OF DYKE
6
PIPELINE WARNING SIGNS
N

DOUBLE JOINTS OF PIPE ARE LIFTED INTO THE TRENCH AND WELDED ONTO THE MARINE SECTION OF THE PIPELINES UNTIL THEY EXTEND INSHORE TO THE START OF THE LANDLINE SECTION. THE TWO PIPELINES ARE HYDROSTATICALLY TESTED.

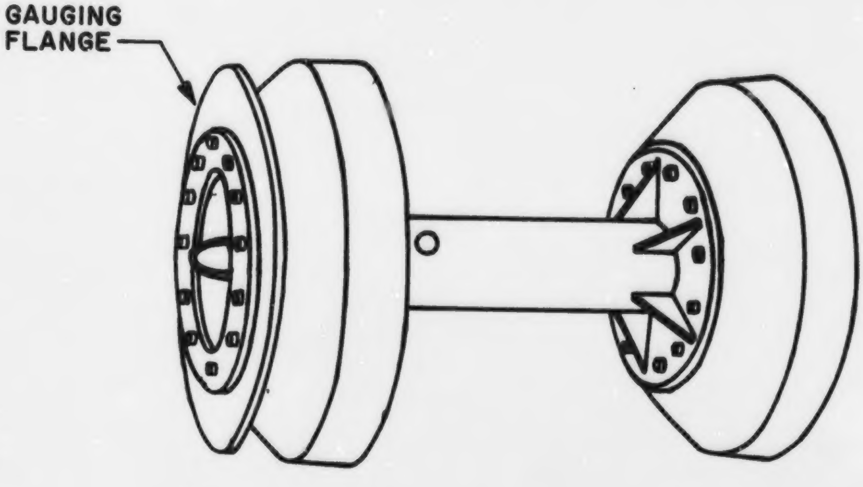
THE TRENCH IS BACKFILLED RESTORING THE DYKE TO ITS ORIGINAL PROFILE.

THE COFFER DAM IS REMOVED, THE BELLHOLE IS BACKFILLED AND THE DYKE IS RESTORED TO ITS ORIGINAL CONDITION. THE BACKFILLING OF THE SHORE APPROACH TRENCH IS COMPLETED AND THE LAND BASE EQUIPMENT DEMOBLIZED. PIPELINE WARNING SIGNS ARE THEN ERECTED.

PLATE 5-21
B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT
SEQUENCE OF OPERATIONS FOR CROSSING DYKE



(a) BASIC PIG
SERVES AS A BATCHING AND DEWATERING PIG



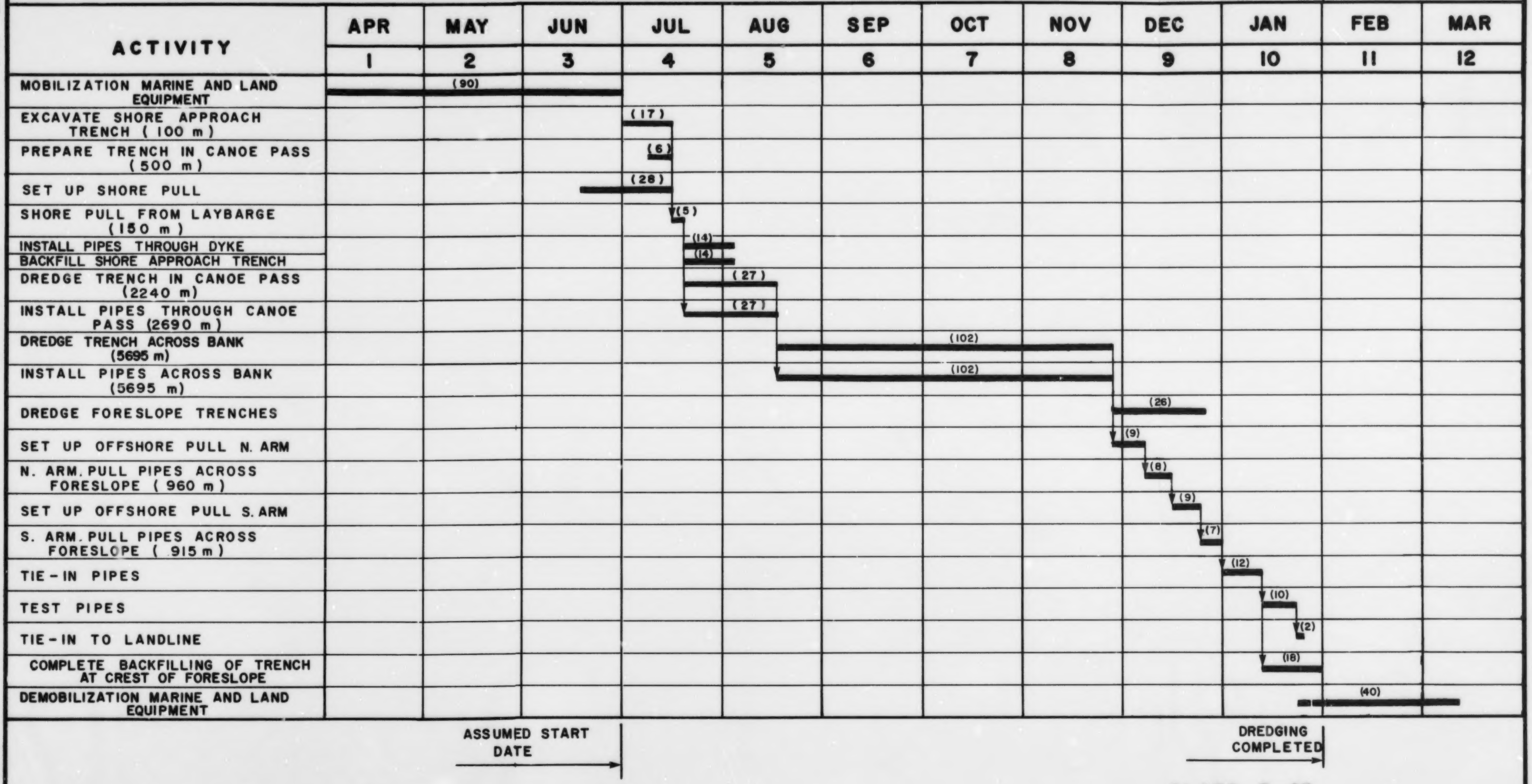
(b) GAUGING PIG

PLATE 5-22

B. C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

BASIC AND GAUGING PIPELINE PIGS

MONENCO PIPELINE CONSULTANTS LTD.



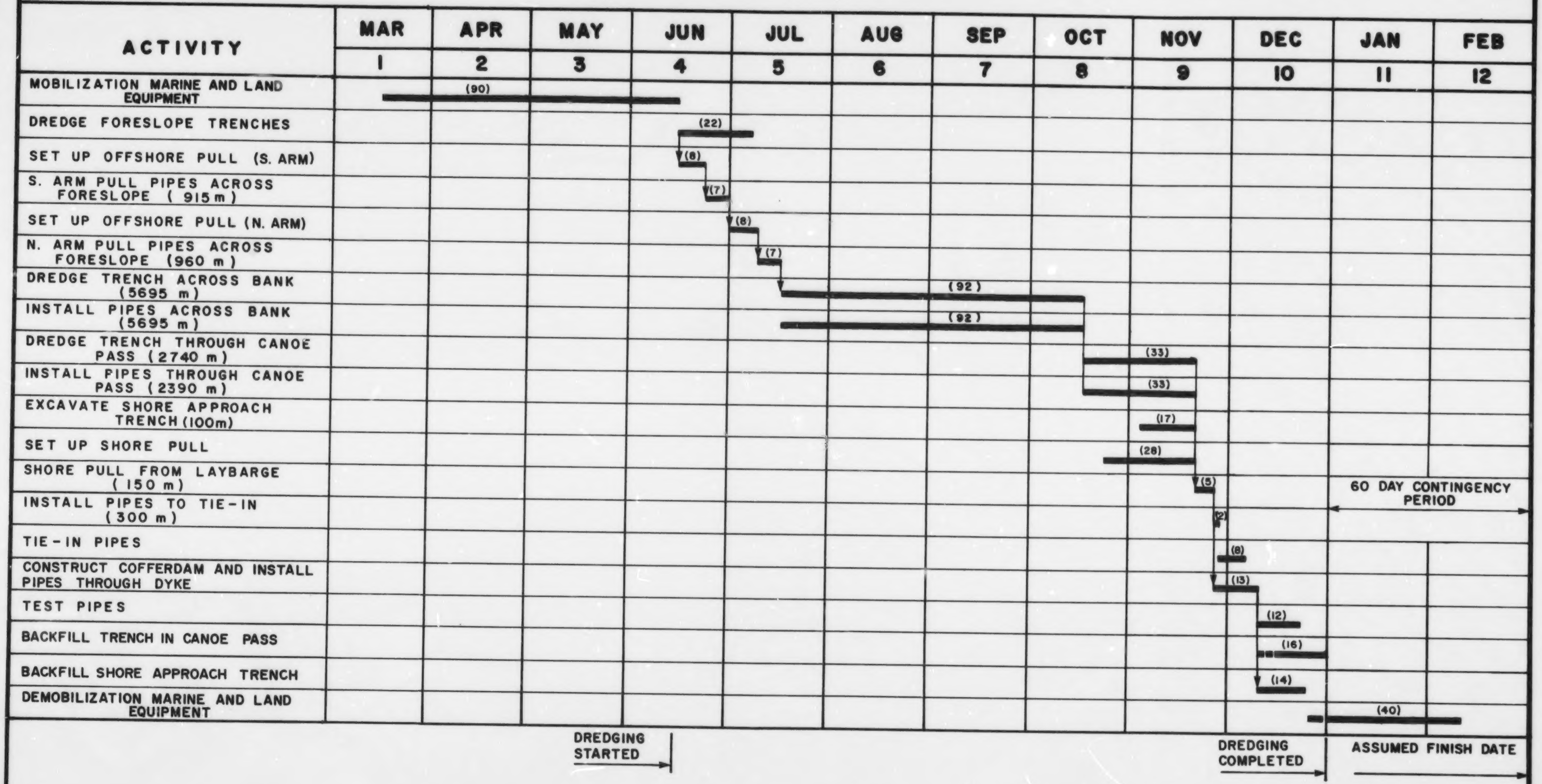
( ) NUMBER OF CALENDAR DAY

PLATE 5-23

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

SEAWARDS CONSTRUCTION SCHEDULE

MONENCO PIPELINE CONSULTANTS LTD.



( ) NUMBER OF CALENDAR DAY

PLATE 5-24

B.C. HYDRO AND POWER AUTHORITY

VANCOUVER ISLAND GAS PIPELINE PROJECT

LANDWARDS CONSTRUCTION SCHEDULE

PART 6

IN-SERVICE OPERATION

PART 6 - IN-SERVICE OPERATION

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6.2 MAINTENANCE 6-2

6.3 REPAIR PROCEDURE 6-2

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  632 Repair Procedure 6-3

6.1 INSPECTION

Those sections of the marine crossing which are not buried would be inspected visually every year using a submarine vehicle to check for line movement, development of free spans and damage to the coating.

For the Roberts Bank section, an annual photographic record of the area would be made, at an extreme low tide following the annual freshet. This would then be compared with the previous records to check for indications of channel splitting or directional changes by Canoe Pass. Also, at yearly intervals following construction, a bathymetric survey would be carried out along the pipeline route and within Canoe Pass to check for scour holes.

Internal inspection would be carried out by means of Kaliper pigs run annually. These pigs measure and record internal diameter, and therefore serve as a check for any dents or buckles.

The interval between inspections would be increased, if no unusual features were observed after the first few years.

6.2 MAINTENANCE

The pipelines themselves should be maintenance free unless damaged by a third party, which is considered extremely unlikely. However, it is possible that some maintenance work would be required to fill any deep scour holes that may occur in the bed of Canoe Pass close to the pipeline. It would be desirable to fill these before they uncover the pipelines as deep scour holes would expose the pipelines to the risks of third party intervention, or free spanning. The filling would be accomplished by dumping coarse sand from bottom dumping scows.

6.3 REPAIR PROCEDURE

631 PROBABILITY OF DAMAGE

It is extremely unlikely that a repair to the pipelines would ever be required, because a high standard of quality control would be maintained at all stages of production and installation, as follows:

(i) The pipe would be 100% inspected at the pipe mill by x-ray, or similar means, to check for internal defects.

(ii) Also, at the pipe mill, each joint would be individually tested to a pressure greater than that used for the final pipeline hydrostatic test.

(iii) The corrosion coating would be tested electrically at the coating plant to ensure complete insulation of the line.

(iv) Each weld would be 100% inspected by x-ray on the laybarge, to check for internal defects.

(v) A buckle detector would be towed in each line as it is laid, to ensure that the pipeline had not been deformed in the laying process.

632 REPAIR PROCEDURE

In the unlikey event, that one of the pipelines failed the hydrostatic test, then the repair would be undertaken in the following manner.

.1 Locate the Leak

The line would first be filled with water and a bright dye mixed into it. Then the line would be pressurized, and the water surface would be watched for traces of the dye. If that was unsuccessful the line would be pressurized with air and the water surface would be watched for bubbles. If neither of these techniques were successful, then there are a range of sophisticated accoustic devices for listening for escaping air or water. The ease with which the leak would be located would clearly depend on the size of the leak.

.2 Expose the Pipe

The technique used for this operation would depend largely on the location of the leak. A leak in Canoe Pass or on the foreslope would be relatively straight forward. A hole approximately 50 m x 50 m would be excavated to a depth of 1 metre above the top of the pipe, by means of a small cutter suction dredge. Then divers using hand held tools would completely expose the line. However, should the leak occur in the middle of the intertidal flats, then the dredge might need to dredge an access trench from some point in Canoe Pass to the location of the leak. The excavation procedure would be as before except that the area of the hole would be larger, perhaps 200 m x 200 m, due to the greater depth of cover over the pipe, and the area required for the dredge to manoeuvre.

.3 Repair the Line

A range of standard techniques to complete the repair are available. These include the following: special mechanical connectors; underwater habitat welding; and raising the line above the water for welding. All of these techniques would require a support barge.

.4 Backfill the Hole

The method used would be determined by the location of the leak. In Canoe Pass or on the foreslope, material would be dredged from the immediate vicinity by a cutter suction dredge and the material discharged into the hole using a submerged discharge nozzle. On the intertidal flats it might be necessary to import sand by scow.

The same procedure could be adopted for a leak detected after the pipeline was in operation, with the additional complication that the entire line from Brunswick Point to Valdes Island would have to be inspected to locate the leak.

PART 7

IMPACT ON THE PHYSICAL ENVIRONMENT

PART 7 - IMPACT ON THE PHYSICAL ENVIRONMENT

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7.2 CANOE PASS CHANNEL 7-2
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7.4 FORESLOPE 7-5
7.5 DISPERSION OF DISCHARGED MATERIAL 7-5
7.6 CHANNEL MORPHOLOGY 7-9

IMPACT ON THE PHYSICAL ENVIRONMENT

INTRODUCTION

In general terms the physical impact of the construction on the Roberts Bank area would be of a temporary nature. However, the construction would clearly cause considerable disturbance to the area during the period of construction. The aim would be to keep this physical disturbance to a minimum through close supervision of construction, and to return the area to a condition as close to its original state as possible, consistent with reasonably economic construction practice.

7.1 TIDAL MARSHES

The area of tidal marsh at Brunswick Point that would be affected by the construction is a strip extending from the toe of the dyke to the edge of Canoe Pass channel. Plate 5-16 shows that the width of the shore approach trench varies from 30 m at the toe of the dyke to 85 m at the edge of Canoe Pass. The material excavated from chainage 100 m inwards would be stockpiled on either side and the maximum width of area that would be disturbed is approximately 120 m, with the possible addition of an anchor from the dredge being located to the south of this area.

7.2 CANOE PASS CHANNEL

Within the confines of the Canoe Pass channel the pipelines are buried below the channel bed and would not affect the channel morphology.

Where the pipelines trench enters and leaves the Canoe Pass channel, the channel banks would be destroyed. The pipeline trench would be sealed on the west side of Canoe Pass by a coarse sand plug to prevent any erosion of the Bank, which would reform naturally to its original profile. On the east side erosion is not considered likely and the bank would be rebuilt with material dredged from further down Canoe Pass. The existing slopes of both banks are very shallow at approximately 5% on the west side and 7% on the east side.

During construction the dredge, laybarge and backfill pontoon would be in Canoe Pass for approximately two months. Their anchors would be stretched across the channel and would block Canoe Pass. This would inconvenience any marine traffic, which normally uses Canoe Pass, as it would have to take the alternative Main Arm route.

If the landwards construction sequence was adopted a shortfall of backfill material would be generated at Brunswick Point. Therefore, to complete the backfilling of the trench, suitable material would be dredged from the reaches of Canoe Pass, below Brunswick Point. The volume required would be approximately 220,000 m^3 and would be dredged from the sand banks on the south side of the channel. It is not envisaged that this dredging would affect the channel structure, and a small benefit to the marine traffic using the channel would occur.

7.3 INTERTIDAL FLATS

Across the intertidal flats the trench width would vary up to a maximum of approximately 90 m. The total width disturbed would be approximately 200 m, as anchors would be placed each side of the trench, and work boats and barges would sit on the flats at low tides.

Plate 5-12 shows a typical trench cross section through the intertidal flats and the width of working area reserve required.

After the pipelines had been laid the trench would be backfilled to give a small (0.5 m) hump above local bank level. It would be undesirable to leave a depression over the pipes, as this would act as a natural channel for tidal flows and waves which could cause scour. Because the accuracy of the backfill operation would be dependent on operator skill, and the operators would probably have never performed exactly this operation before, a completely smooth surface would be unattainable, especially at the start of the job. However, it is likely that the action of waves and currents would smooth out any ridges or hummocks in a matter of days.

Previous experience indicates that sandy material consolidates very quickly. Only a few minutes would be required for complete consolidation of clean sand. For Roberts Bank soils, comparison of the density of the backfill material, assumed to be in its loosest state, with the average density of the in-situ material, indicates that settlement of no more than 0.6 m would occur. However, because of the very slow rate of progress of the backfill operations, (approximately 60-100 m per day), it is probable that most of this settlement would take place as the backfilling continues, and therefore would not be noticed. Any further settlement would be slight and would be expected to occur in the first year after construction. This would either reduce the height of the slight hump over the ditch, or be compensated for by the action of waves and currents dispersing material across the flats.

7.4 FORESLOPE

Coarse sand plugs would be placed in the pipe trenches at the -13 m GSc contour on the foreslope, to ensure the stability of the backfill material inshore of these points. The remainder of the ditches down the foreslope would be allowed to backfill naturally.

This infilling of the trench would occur as a result of the gravity infill of the bed load, and the settlement of some suspended sediment due to the decreasing current velocity and wave action within the dredged trench. However, should the first annual inspection following completion of the installation show that this was not occurring, a dredge would be remobilized, and backfill material dredged from close by on the foreslope. The material would be placed either using bottom dump scows, which would result in high losses of 50 to 100%, or else through some type of extended drop tube arrangement.

7.5 DISPERSION OF DISCHARGED MATERIAL

The characteristics of the discharge plume and its turbidity are controlled by the interaction of the particle size distribution, particle settling rates, discharge rate, water depth, current velocities, and the diffusion velocity.

Low concentrations of silt and clay material (with particle diameters of less than 0.03 mm) settle very slowly causing large, persistent turbidity plumes. Where there are high concentrations of clay minerals, the particles may coalesce to form aggregates, or flocs, with diameters of 0.1 to 2 mm which settle more rapidly. The degree of flocculation increases rapidly as the salt concentration increases from 0 to 10 g/l, and remains essentially constant from there up to 35 g/l, the concentration of seawater.

The salinities of the water over Roberts Bank have been measured as 11 g/l at Brunswick Point and 20 g/l midway across the intertidal flats which would be sufficient to cause a high degree of flocculation. However, the majority of material to be dredged has less than 3% of clay material, which is not sufficient to cause flocculation. In addition the balance of the sediments are thought to consist of quartz and rock fragments which would also not flocculate. These clay particles would enter the plume and would be carried away by any current in the water.

Over the majority of the route, the percentage of silt material is less than 10% although small layers are present with percentages of 10 - 25% or greater.

An approximate "worst case" prediction of the shape and dimensions of the plume, and the average concentration above background of suspended solids along the length of the plume, has been prepared. It is based on a method proposed by the U. S. Corp. of Engineers Waterways Experiment Station(12).

The results were obtained using the following criteria. The rate of discharge of solid material from a 660 mm (26 inch) diameter discharge nozzle would be 620 kg/sec. 90% of this material would settle rapidly, while the remaining 10% (62 kg/sec) would be suspended in the plume. The average depth of water over the Bank would be 2.0 m and the mean diameter of dredgate would be 0.2 mm. The nozzle would be raised above the local bank level for a total of 4 hours, 2 hours before and 2 hours after high tide. The average current speed would be 0.66 m/sec.

Factors such as discharge nozzle configuration, and the prevailing weather conditions, although relevant, were not considered in the calculation due to their complex and quantitatively unpredictable effect on the plume characteristic. The calculation assumes that the material would be discharged onto the water surface. This is a more severe condition than if the nozzle is located 0.5 to 1.0 m below the water surface.

The results showed that during the 2 hour period immediately before or after high tide, the plume would have stretched a distance of 4.7 kilometres in the direction of the tidal current, and would be approximately 1 kilometre across at its widest point. However, 1.7 kilometres from the nozzle the concentration of solids would be less than the average background concentration of 25 mg/l. Therefore the majority of the plume would have a solids concentration below that of the average background concentration. The pipeline route runs parallel to the direction of the flood and ebb tidal currents. Therefore for one of the tidal cycles most of the material suspended in the plume would settle out in the "bathtub", but in the other direction the plume would stretch across the bank.

If the landwards construction sequence were adapted the stronger flood tide current would carry the sediment into the "bathtub", while the ebb tide current would carry the material towards the Straits of Georgia and away from the Banks.

For approximately ½ hour as the tide changes the current would be at right angles to the trench and a small plume would occur to the south.

On the outer edge of the foreslope the discharged material would be subject to more severe winds and waves which would tend to spread any sediment in suspension from the backfilling operation over a wider area.

7.6 CHANNEL MORPHOLOGY

It is not envisaged that the construction of the pipelines would have any major impact on the morphology of Canoe Pass Channel. The dredged material lost during the backfill operation within Canoe Pass would be carried in suspension down the channel to settle out along the way. The estimated volume of dredgate which could be lost is 20,000 - 40,000 m^3 per month for a period of 1 - 2 months. The increase in sediment load would only be of a temporary nature, and small local changes in features may occur along the channel. To prevent a major migration of the channel along the backfilled trench, it would be sealed at the point where the route passes through the northern bank of Canoe Pass. To prevent the backfilled trench developing into a channel for the incoming and outgoing tides the trench would be backfilled to give a small (0.5 m) hump above local bank level. The proposed construction method is not envisaged to adversely influence the features of the channel so as to cause a major migration. However, any channel passing through a delta area is able to migrate and a combination of natural factors may be sufficient to cause the channel to move in the future. Therefore the burial depth of the pipeline has been designed with this possibility in mind.

APPENDIX A

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Volume

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ENVIRONMENTAL IMPACT ASSESSMENT
OF
CONSTRUCTION
OF A NATURAL GAS PIPELINE
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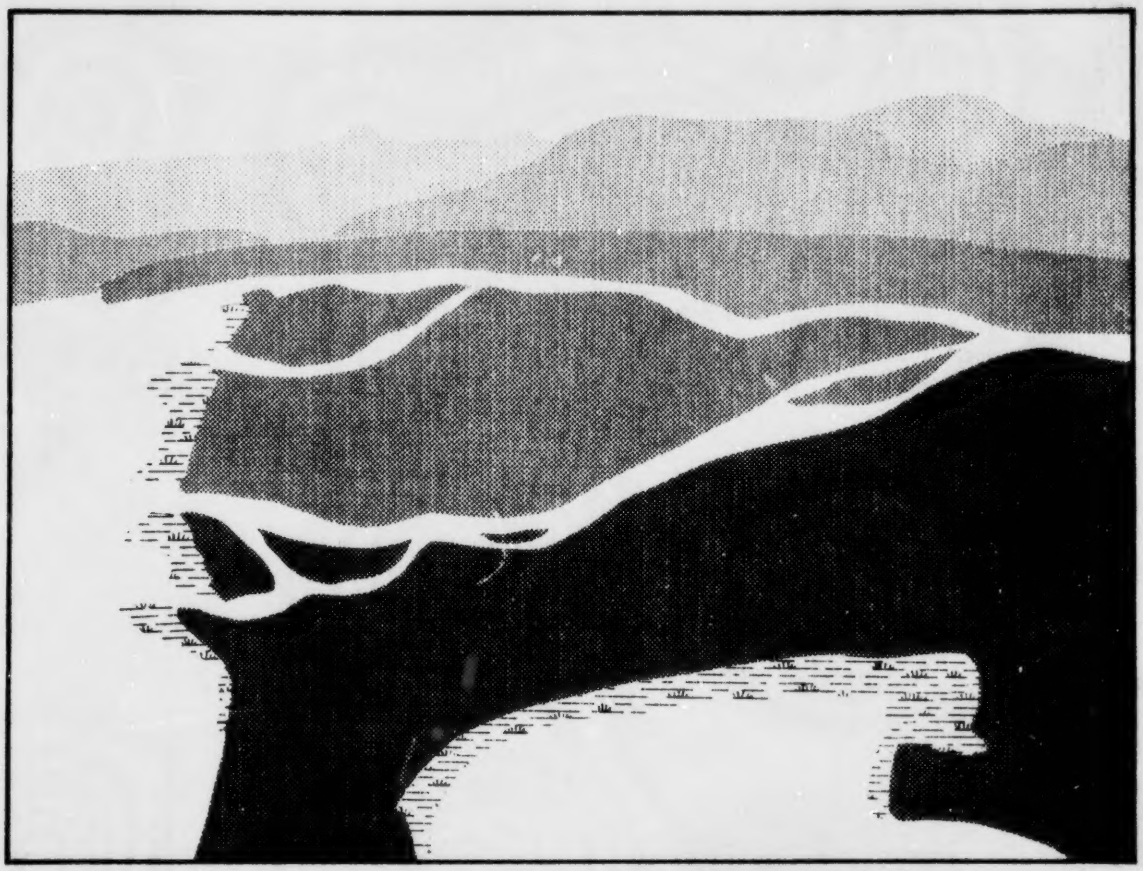

Volume 3: The Impact of Pipeline Construction on the Aquatic Ecosystem of Roberts Bank

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ENVIRONMENTAL IMPACT ASSESSMENT OF CONSTRUCTION OF A NATURAL GAS PIPELINE ACROSS ROBERTS BANK

VOLUME 3

THE IMPACT OF PIPELINE CONSTRUCTION ON THE AQUATIC ECOSYSTEM OF ROBERTS BANK

B. C. HYDRO
FEBRUARY, 1983

R. U. KISTRITZ AND B. J. HARRISON
R. U. KISTRITZ CONSULTANTS LTD.

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ADDENDUM

This report has remained in final draft status for one year, from February 1982 to February 1983. During that time, the report was reviewed by B. C. Hydro and by members of the OIC 908 Technical Assessment Committee (OIC 908 TAC). During deliberations between B. C. Hydro and the OIC 908 TAC, a number of questions and concerns pertinent to the contents of this report were recorded. The purpose of this addendum is to address these key questions and concerns.

It should be recognized that reviews and analyses of scientific information presented in this report were conducted more than one year ago. Questions and concerns addressed by this addendum are therefore discussed only in the context of what was known up to the preparation of the final draft report in February 1982.

The substance and major conclusions presented in this report remain as originally drafted. Minor revisions have been made to correct typographical errors and to provide clarifications on figures, tables, and text. In response to key questions and concerns expressed by the OIC 908 TAC, the following answers are provided:

1. Why were juvenile Dungeness crabs excluded from critical life history stages?

   The importance of all life history stages is described in Section 2.5.1.7 and the relative seasonal sensitivity of juvenile crabs is included in Figure 3.4-1. However, the main reason for highlighting the moulting and mating life history stage above all is that crabs are particularly vulnerable to physical disruptions during that stage of their development; first of all because they tend to be aggregated on the sand flats during the mating period and secondly because soft-shelled crabs are less mobile and more susceptible to physical injury.

2. Could the losses of benthic biomass due to dredging be much higher in Canoe Pass than the 1 percent estimate made for Roberts Bank?

In a purely geographical context, the proportionate losses of benthos in that part of the study area desigrated as Canoe Pass would indeed be greater than the proportionate loss on Roberts Bank. However, Canoe Pass itself represents only a small portion of the total riverine habitat potentially available in the lower Fraser River.

3. Will there be a loss to the local crab population for some period of time as a result of dredging related mortality?

Crab populations, like most marine invertebrate populations exhibit life-cycle adaptations which maximize reproductive outputs because natural mortalities are often catastrophic and unpredictable. The planktonic dispersal and settlement of crab zoea would contribute to the natural, long-term (i.e., 5 to 6 years) replenishment of a localized population which had suffered high mortality. Also, since adult crabs are highly mobile and opportunistic, local immigration would contribute to the short-term (i.e., one year) replenishment of a decimated population.

Stevens' (1981) study of dredging related crab mortality in Gray's Harbour Washington showed that normal densities of crabs were evident one year after dredging had occurred. It is apparent from this study that recruitment from immigration was sufficient to re-establish populations to pre-impact levels.

4. Why can the dredging schedule not correspond precisely to the period considered least sensitive to the aquatic resources of Roberts Bank; namely late October to early February (cf. Figure I, p.x)

This question is beyond the scope of this report since it requires a full rationalization of the actual engineering and economic constraints of the proposed pipeline project. However, the point of reference used for selecting the overall environmental considerations of project scheduling was the landwards and seawards construction schedule alternatives as reported by Monenco (1981).

It was obvious from these two alternatives that the proposed six or seven month dredging period would not fit into the 3 to 4 month environmentally least sensitive period identified for Roberts Bank (Figure I). The landwards schedule was considered to be less environmentally disruptive than the seawards schedule for reasons stated in this report. Furthermore, it was recognized that there would be unavoidable impacts to crab and fish populations on the foreslope and intertidal sandflats. However, the landwards schedule would offer maximum protection of valuable inshore resources such as migrating adult and juvenile salmon and marsh habitat.

R. U. Kistritz

Richmond, B. C.
February, 1983

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Rough drafts of this report were reviewed by K. J. Hall (Sediments and Water Quality Sections) and T. G. Northcote, (Fishery Resources Sections), UBC, Westwater Research Centre. We are most grateful for their helpful comments and criticisms.

EXECUTIVE SUMMARY

Existing Environmental Conditions of Roberts Bank Aquatic Ecosystem

The key components of the estuarine environment along the proposed pipeline route (PPR) which are considered in this report are sediments, water quality, marsh habitat, benthic communities and fish. Information about these components was examined for considerations which would be most critical in the interaction of dredging and pipeline construction with the aquatic ecosystem along the PPR.

(i) Sediments

Sediment characteristics critical in consideration of environmental effects of dredging and aquatic disposal of dredged material pertain primarily to geochemical aspects of the dredged material. A knowledge of existing geochemical conditions along the PPR made it possible to postulate potential problems related to the release of toxic contaminants, the consumption of dissolved oxygen, and the increase in turbidity.

Results of bulk geochemical analyses of 46 sediment samples taken at various depths (up to 8 m) along the PPR showed that measured values of toxic contaminants such as trace metals, organohalogens, and soluble sulphide were relatively low and generally fall within the range of values reported in the literature for Fraser estuary sediments located away from pollution sources.

The percent chemical oxygen demand of sampled sediment was considerably below values of 5 to 10% typical of polluted or highly organic sediments. The percentage of fine grain size particles (<63 μm) was generally less than 10% with the exception of surface samples from marsh sites which averaged around 82%.

(ii) Water Quality

Water quality considerations important to the understanding of sediment-water interactions resulting from the aquatic disposal of dredged material are: turbulent mixing, salinity, suspended sediment, pH, and dissolved oxygen. Computer data files from three representative water quality monitoring stations in the Fraser estuary were analysed to characterize the type of water mass influencing the general vicinity of the PPR. Water masses exhibit characteristics of well mixed conditions during strong tidal currents and winds as well as stratified conditions near slack tide. Suspended sediment concentrations range from low values of 2.0 mg l^{-1} in saline water to 100 mg l^{-1} in fresh water during the Fraser River freshet. Water is well oxygenated, moderately buffered, of low to moderate productivity (nutrients) and with widely fluctuating salinity (0 to 30 ppt) and temperature (2.6 to 20°C) conditions. There are no existing water pollution problems reported for the immediate area of the PPR.

(iii) Marsh Habitat

The marsh habitat at Brunswick Point shore approach is recognized as a critical environment for juvenile salmon and for estuarine productivity in general. Plant-environment relationships with substrate elevation, and stability are the two most critical considerations with respect to this project. Vegetation occurs from the toe of the dyke to approximately minus 0.5 m Geodetic elevation where the marsh gradually merges into bare mudflat. Within the approximately 2 ha area of marsh which can potentially be affected by pipeline construction activities, Lyngbyei's sedge represents the most dominant vegetation community. Dominant vegetation communities are mapped showing elevation contours to within ±0.25 m.

(iv) Benthic Communities

A total of 62 different groups (taxa) of benthic and epibenthic organisms are recognized in the vicinity of the PPR within four distinct habitat zones: the delta foreslope, the intertidal sandflats, the riverine habitat of Canoe Pass, and the marsh/mudflat of Brunswick Point shore approach. Each of these zones contains a different assemblage of dominant benthic organisms and specific details of numerical abundance, percent composition and biomass (wet weight) are given in this report.

Generally, the highest benthic biomass is found in the marsh/mudflat and delta foreslope zones with the intertidal sandflat zone being lower by more than an order of magnitude. Invertebrate diversity, on the other hand, is highest at subtidal sites in Canoe Pass and on the delta foreslope. Benthic communities of the riverine (Canoe Pass) and marsh/mudflat zone appear to support prey items favoured by fish whereas the high production of small clams (Macoma) in the benthos of the sandflats would be more favourable to the Dungeness crab.

Two critical periods identified for the Dungeness crab are times of moulting (soft-shell) and mating (generally April through to September) occuring in shallow subtidal and lower intertidal areas of the PPR; i.e. mainly the delta foreslope and outer intertidal sandflat zones.

(v) Fishery Resources

Life history, estuarine use patterns, and trophic relationships are detailed for 15 important estuarine fish species. The five species of Pacific salmon are considered to be the most important component of the estuarine fish community because of their migratory behaviour and critical estuarine rearing period during the juvenile stage of development. Chum and chinook salmon fry are most abundant from March through to early July especially in the Canoe Pass area and adjacent marsh creek systems. Maximum activity of adult salmon migration is between June and October. Peak salmon catches for the Canoe Pass Indian Food Fishery also fall within this period.

In terms of the overall importance of the four major habitat zones recognized along the PPR (marsh/mudflat, riverine, intertidal sandflat, delta foreslope) to adult and juvenile salmon, the marsh/mudflat and riverine zones rank as the most important. These two habitat zones also support the most important food items for chinook, chum, and sockeye salmon fry, staghorn sculpins, and starry flounders.

Probable Impacts of the Project on Roberts Bank Aquatic Ecosystem

The most common concerns expressed in the scientific literature pertaining to environmental effects of dredging and open-water disposal of dredged material were examined in light of the technical details and expected physical effects of this project. Mitigation measures, especially with respect to project scheduling, are suggested where critical interactions were perceived between dredging operations and aquatic resources. The main conclusions of the impact assessment are summarized in point form.

(i) Water Quality

1. Increased turbidity and suspended sediment will probably be the main water quality impact of any appreciable magnitude. A turbidity plume may be apparent up to 1 km from the point of discharge of dredged material under periodically occurring extreme conditions, i.e. high tide, strong currents, in winter time.

2. Dissolved oxygen levels are expected to remain relatively unimpaired except during the short bathtub isolation period when levels in the main water column may diminish by approximately 1.9 mg l^{-1}. Near the sediment-water interface dissolved O_2 may become depleted to levels approaching zero.

3. Toxic contaminants are not expected to be released from dredged material and accumulated in the water column to levels which might become detrimental to aquatic organisms.

4. Special attention will be required to ensure that hazardous chemicals stored, transported or used during construction do not interact with Roberts Bank ecosystem. Appropriate containment and cleanup measures should be on stand-by throughout the duration of the pipeline project.

5. No scheduling restraints or other mitigation measures are recommended in addition to the techniques already described by Monenco (1981) for mitigating losses of fine suspended material during dredging.

(ii) Marsh Habitat

1. Shore approach construction activities at Brunswick Point will temporarily (maximum 45 days) remove for storage approximately 8,500 m^2 of marsh habitat and could potentially disrupt an additional 15,500 m^2 within the 120 m wide working area.

2. The degree of long-term impact will depend largely on the success of restoring backfilled areas. If surface soils containing roots and rhizomes are saved and stockpiled prior to excavation and returned to original locations after backfilling, a good recovery of plant growth is anticipated. A back-up of transplant vegetation should be available to fill in any remaining bare areas if necessary.

3. Particular care needs to be taken in the handling of petroleum hydrocarbon products in and around the marsh. Oil spills in marsh environments usually result in plant mortality and growth impairment which may be evident for several years.

4. The late autumn and winter plant dormancy period is suggested to be the most favourable period for construction activities to take place. It is recommended that a preconstruction vegetation survey and post-construction restoration monitoring programme be conducted to ensure the success of marsh restoration.

(iii) Benthos and Crabs

1. Losses of benthic resources in the direct path of dredging will be almost total and unavoidable with losses amounting to approximately less than 1% of the total estimated benthic resources of Roberts Bank intertidal sandflats. Losses for specific habitat zones such as the riverine zone of Canoe Pass may be higher. Estimated benthic biomass losses are reported for each habitat zone. Direct mortality to crabs is expected to be greatest during peak moulting and when the population may be concentrated for reproduction (May to July). Based on evidence of dredging effects in Gray's Harbor (Stevens, 1981), re-establishment of benthic populations and normal crab densities, whether from natural recruitment or from immigration from surrounding areas, can be expected within one year after dredging.

2. Indirect impacts of the dredging operation on the benthic environment include activities due to support vessels, anchors, etc., creation of a suspended sediment plume, and burial by drifting sediment or dredged material stockpiling. These impacts would be relatively minor in comparison to the anticipated losses of benthic production in the direct path of the dredger. Moreover, no lasting environmental degradation is expected to occur since partial recovery of the benthos is expected within the first few months after dredging with full recovery of an "equilibrium" community requiring approximately one year.

3. Fall and winter dredging will promote the most rapid recovery of the benthic community and would also be least damaging to crab populations along intertidal and shallow subtidal portions of the pipeline route. Dredging on the foreslope near the winter period could, however, result in mortalities of crabs known to exist in significant numbers at the drop-off area of the foreslope.

4. The "bathtub" method of dredging and backfilling is expected to result in some long-term changes in the physical characteristics of sediments (i.e. increased grain size) inhabited by benthic organisms which could result in

a "climax" community different from original conditions. This effect would be evident mainly in deeper levels of the benthic community since surface sediments are expected to regain their original characteristics with the first winter storms and river freshet period after dredging is completed.

5. It is suggested that overall mortality to benthic organisms and crabs would be reduced if a splash plate is not used on the discharge nozzle.

(iv) Fish

1. Salmon fry entrainment into the dredger intake would be potentially greatest in areas where they are most confined or concentrated, namely: Canoe Pass and Brunswick marsh area. This area also appears to be particularly sensitive to construction activities because of upstream migrating salmon and the associated salmon gillnet fishery. The "bathtub" itself is another location where, because of its potential "attraction" to fish, entrainment may become relatively high.

2. The indirect impact on commercially important fish species due to the temporary disruption of potential food organisms is considered to be of minor or negligible consequence. The most notable exception is starry flounder which feed on those benthic organisms which are likely to be most heavily impacted by dredging.

3. Potentially adverse interactions between dredging activities and salmon can be appreciably reduced and in many cases avoided by proper scheduling. A dredging period least sensitive to fish appears to be mid-June to mid-February (marsh/ mudflat), December to mid-February (Canoe Pass), and early September to late January (delta slope and outer sandflats).

4. Because fish are present in the estuary throughout the year, some fish mortality as a direct result of construction activities is inevitable. In addition to the scheduling suggested above, other mitigation techniques may prove effective particularly for deterring fish from entering or residing

in the bathtub: chemical repellents and electrotaxis may be most effective with bubble curtains as a possible but less effective alternative. Special procedures in operating the dredger are also recommended to minimize entrainment of fish by the cutter suction head.

Project Scheduling: Overall Environmental Considerations

The landwards and seawards construction schedules reported in Monenco (1981) were the result of a series of refinements which took into account preliminary considerations of the effects of pipeline construction on the ecology of Roberts Bank. The project actions (eg. routing, scheduling, techniques) detailed by Monenco (1981) served as the basic framework for the environmental impact assessments stated in this report.

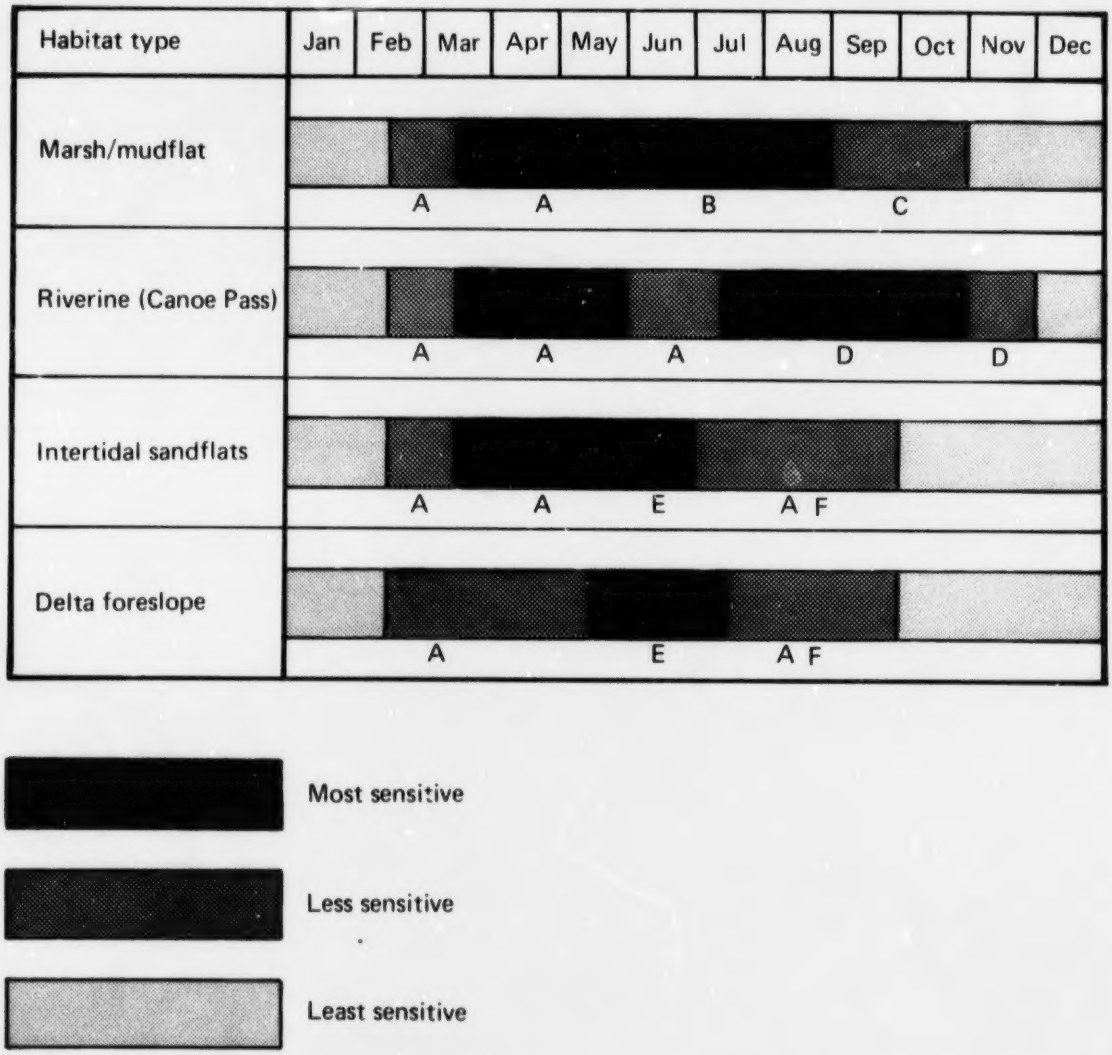
Scheduling of pipeline construction activities (notably dredging operations) to fit into time periods when probable environmental impacts are considered to be least damaging to the Roberts Bank ecosystem was recognized as the most effective mitigation alternative available. Figure I summarizes critical aspects pertaining to all of the considered aquatic resource components in each of four main habitat zones in order to show possibilities for a most preferred dredging window.

Clearly, neither the landwards nor the seawards construction schedule reported by Monenco (1981) is without any conflict with a "most or less sensitive" period shown in Figure I. In the landwards schedule, a potential interaction would arise during the start of dredging in mid-June and July when crabs are known to be relatively vulnerable to dredging impacts because they are moulting and aggregated for mating in the shallow subtidal and lower intertidal areas of Roberts Bank (see Section 3.4 for further details). A later dredging start-up to avoid crab-related impacts would increase the risk of interacting with the start of salmon fry migration in March.

Figure I

Relative seasonal and spatial sensitivities of critical aquatic resource components of Roberts Bank ecosystem to potential interactions with the pipeline project.

A - Salmon fry and smolt migration and rearing
B - Peak aboveground standing crop of marsh vegetation
C - Root and rhizome energy storage in marsh
D - Major salmon spawning runs
E - Crab moulting and mating
F - Juvenile crab settlement



In the start of the seawards construction schedule, there may be potential impacts on the major adult salmon runs using Canoe Pass in August and September. This period is also less desirable for best results in restoring disturbed marsh vegetation at Brunswick Point shore approach. To avoid these probable impacts, dredging would have to begin in late October which would probably bring dredging on the outer delta into conflict with moulting and mating crab populations.

It appears that with the maximum protection of inshore resources (juvenile and adult salmon, and marsh habitat) by avoiding dredging in Canoe Pass and Brunswick marsh shore approach area from February through to October, a potential interaction with crabs in the outer delta during their sensitive moulting period is unavoidable.

As it presently stands, the landwards construction schedule is preferred over the seawards schedule since it provides fewer overall potential impacts with aquatic resources, especially those found inshore along the PPR. The seawards schedule would be an acceptable second choice only if dredging started in late October.

Monitoring and Assessment

Three considerations for environmental monitoring are recommended as appropriate to this project.

1. The Brunswick marsh shore approach area should be surveyed prior to construction, supervised during vegetation stockpiling and backfilling, and monitored after restoration to determine the success of restoration and to provide the necessary feedback information needed to determine if additional plantings or erosion protection measures should be undertaken.

2. Pre-construction surveys of benthos should be conducted along the PPR followed by post-construction monitoring to determine rates of recovery of benthic communities. This monitoring study would provide valuable case history information in assessing the environmental impact of a repair procedure in the remote chance that one of the pipelines failed. The monitoring results would also be of value in other future environmental impact assessments pertaining to disruptions of Fraser estuary tidal flats.

3. Measurements of entrainment and mortality of fish and crabs via dredging would provide useful case history information as well as providing a valuable assessment of mitigation techniques used in this project to minimize entrainment and to repell fish and crabs.

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1.0 GENERAL INTRODUCTION

1.1 Purpose and Scope

This report serves as part of the input necessary for an environmental impact assessment (EIA) of the crossing of Roberts Bank by B. C. Hydro's proposed Vancouver Island Natural Gas Pipeline. Under the provincial government's Order-In-Council 908, an EIA is required for approval of this project within the designated area of Roberts Bank.

The original Terms of Reference proposed by B. C. Hydro Gas Group for this study are attached to this report in Appendix 6.1. The Terms of Reference provided the basic scope for this study. Since the available data base was considered adequate for the purpose of this study, field sampling programs were not designed or undertaken as specified in Terms of Reference Nos. 2.3, 2.7, and 2.9 (see also discussions in Section 1.3).

1.2 Study Area

The designated study area of Roberts Bank is bounded in the north by Steveston Jetty, in the south by the coal port causeway (Westshore Terminals), in the east by the dykes, and in the west by the toe of the delta foreslope (Figure 1.2-1).

Within the previously described designated study area of Roberts Bank four zones are recognized, representing notably different estuarine environments (Figure 1.2-2).

(a) Delta Foreslope: this area is located at the most seaward end of the approximately 9.5 km pipeline route crossing Roberts Bank. This subtidal zone occurs from chart datum, which is only several hundred metres east of the foreslope crest, to the lower foreslope at a depth of approximately 40 m below chart datum.

(b) Intertidal Sandflats: this environment comprises the largest portion (>50%) of the proposed pipeline route, occupying the area between the delta foreslope and Canoe Pass.

Figure 1.2-1

Map of Fraser River estuary showing outline of designated study area on Roberts Bank.

☐ Fraser River

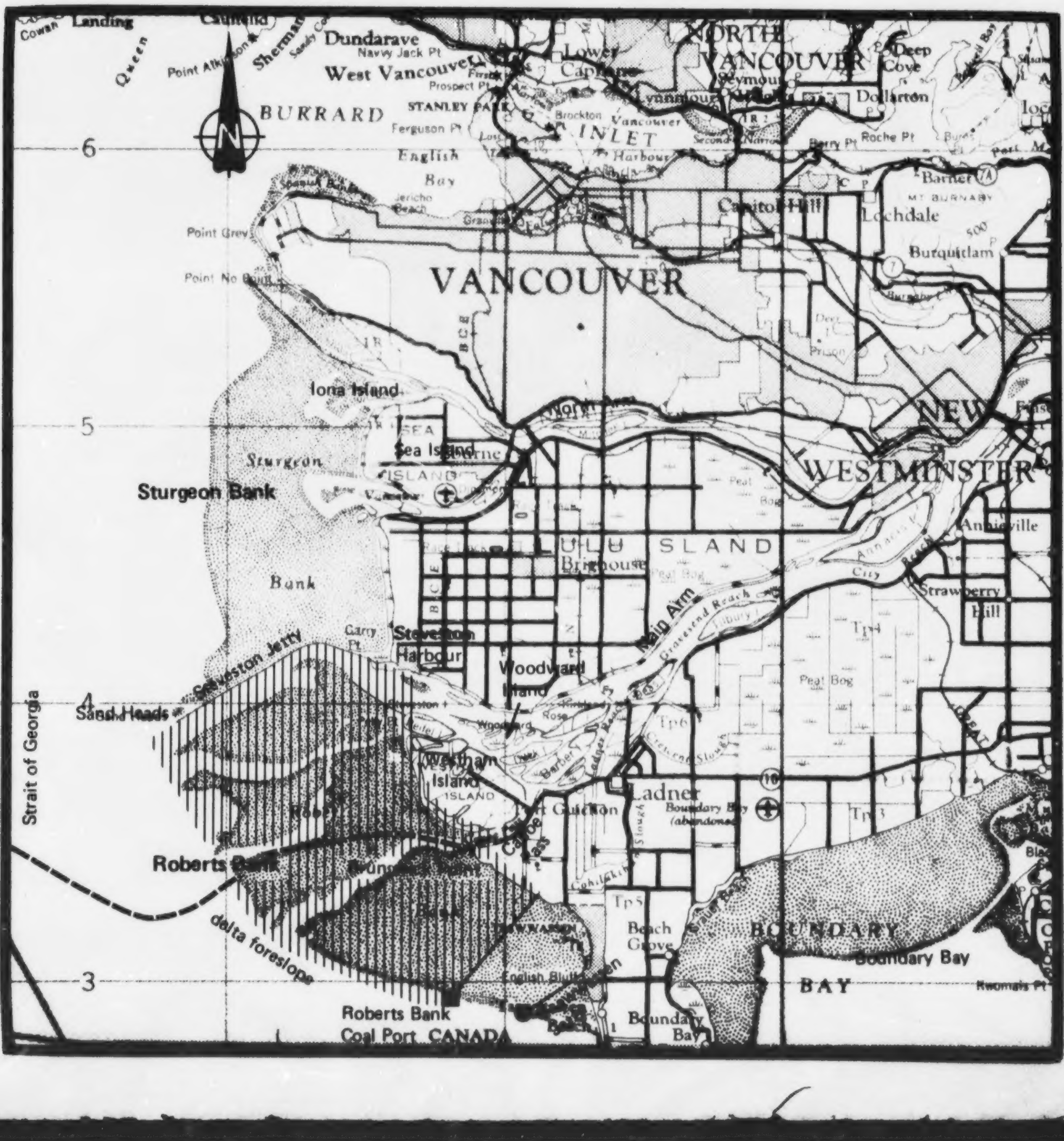
▥ Study Area

☐ Intertidal Banks

- - - Proposed Pipeline Route

0 5 10km

Scale 1:210,000


Cowan
Landing
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Queen
Point Atkinson
Sherman
Dundarave
Navvy Jack Pt
West Vancouver
Prospect Pt
Lower
Capilano
NORTH
VANCOUVER
Deep
Cove
Seymour
Dollarton
BURRARD
STANLEY PARK
Brockton
Ferguson Pt
INLET
Vancouver
Harbour
Second Narrows
Berry Pt
Roche Pt
English
Bay
Barnet
MT BURNABY
Jericho
Beach
Point Grey
Capitol Hill
Lochdale
Burquitlam
Point No Point
VANCOUVER
Iona Island
SEA
Sea Island
ISLAND
Sturgeon
Sturgeon Bank
NEW
WESTMINSTER
Peat
Bog
LULU ISLAND
Brighouse
Annieville
Bank
Steveston
Harbour
Garry
Pt
Steveston Jetty
Main Arm
Gravesend Reach
Strawberry
Hill
Peat Bog
Woodward
Island
Sand Heads
Tp 6
Tp 4
Strait of Georgia
Westham
Island
Ladner
Boundary Bay
(abandoned)
Tp 3
Port Guichon
Canoe Pass
Roberts Bank
Tp 5
Beach
Grove
delta foreslope
BOUNDARY
Boundary Bay
BAY
English Bluff
Roberts Bank
Coal Port
CANADA
Boundary
Bay
Kwomais Pt
6
5
4
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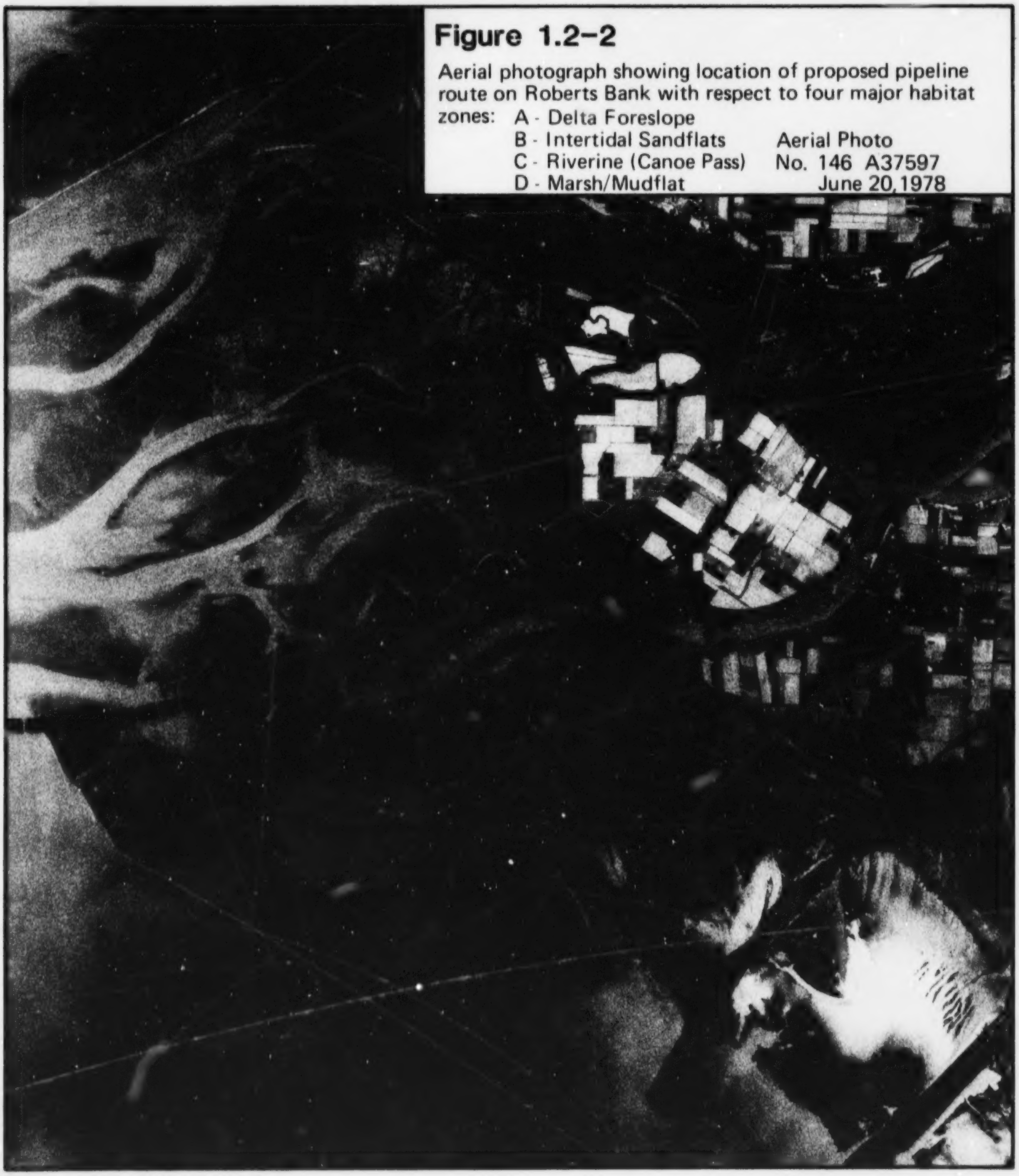

Figure 1.2–2

Aerial photograph showing location of proposed pipeline route on Roberts Bank with respect to four major habitat zones:

A - Delta Foreslope
B - Intertidal Sandflats
C - Riverine (Canoe Pass)
D - Marsh/Mudflat

Aerial Photo
No. 146 A37597
June 20,1978

(c) Riverine: approximately 26% of the pipeline route lies within the subtidal portion of Canoe Pass which is a distributary channel of the Fraser River.

(d) Marsh/Mudflat: approximately 2% of the route is represented by a habitat comprised mainly of marsh vegetation with a small area of bare mudflat exposed at low tide along the south bank of Canoe Pass.

These four major zones along the pipeline route are described in this report with respect to sediment characteristics, water quality, benthic and fish communities, and marsh vegetation.

1.3 Study Approach

The rationale and research strategy of this study were based on several key considerations and fundamental assumptions.

Research Framework: Various project criteria were accepted as the starting point and basic framework of this study. The location of the proposed pipeline route was set as shown in Figure 1.2-1 and only minor adjustments were expected. The bathtub method of construction as reported by Monenco (1981) was accepted as the construction procedure to be used for laying the pipeline. Other construction details given by Monenco (1981) concerning burial depth (5 to 7 m), rate and direction of pipe laying (landwards vs. seawards), and preliminary construction scheduling were addressed in order to develop an overall study approach for determining probable environmental effects of the project on Roberts Bank aquatic ecosystem.

Data Base: It was recognized at the outset of this study that a considerable amount of biological data had been acquired on various aquatic resource components of the Fraser estuary over the past five years. It was therefore necessary to identify the critical interactions which may occur between important aquatic resource components and pipeline construction in order to focus on those aspects of the available data base which would be most relevant to this project. Questions and problems which are most characteristic of this project are those concerned with environmental effects of dredging and open-water disposal of dredged material. In order to address specific questions and problems, in some cases it was necessary to collate and analyse raw data from available studies since information was either in the form of data reports or existing data interpretations were not pertinent to this project.

Field Investigations: Sampling and measuring along the proposed pipeline route was limited to activities which could be readily accomodated within several site visits and which would produce meaningful data relevant to this project.

1. Several surface grab and core tube samples were taken along the proposed pipeline route to provide fresh sediment samples needed to perform laboratory tests to analyse various chemical elements and compounds.

2. Several benthic samples were taken during a helicopter reconnaissance of the pipeline route at a very low tide.

3. The location of dominant vegetation communities were surveyed at Brunswick marsh shore approach.

No attempt was made to launch into any field studies aimed at addressing questions concerned with population dynamics of fish, crabs, or benthic organisms as suggested in the original Terms of Reference proposed by B. C. Hydro Gas Group (Appendix 6.1). From the general knowledge of the aquatic biota in the Fraser estuary it was evident that spatial-temporal variabilities associated with population numbers and patterns of movement are relatively large, particularly for fish, crabs, and benthic populations. Therefore, only a comprehensive sampling effort over several seasons would provide the statistically valid results necessary for making adequate predictions useful in an EIA.

Since the proposed pipeline project would not result in any permanent structures, the major emphasis was on the environmental effects of short-term impacts and any possible measures to avoid or mitigate these impacts, especially through scheduling of construction activities. It was felt that a rigorous examination of the available data base would adequately satisfy these considerations.

2.0 EXISTING ENVIRONMENT

2.1 Introduction

The rigorous examination of available knowledge of the study area serves as the essential anchor point of this report. The identification and relevance of potential environmental impacts of the pipeline project are largely developed through a clear understanding of what we do and do not know about the existing estuarine environment of Roberts Bank.

Some of the information contained in this section originated from unpublished documents or through discussions with scientists who were particularly familiar with specific topics relevant to our investigations. Generally, much of the information available on various environmental aspects of the Roberts Bank ecosystem is in the form of raw data with little if any interpretive discussion. The main task for this section of the report was to analyse the available data in order to synthesize a structural and functional overview of the Roberts Bank ecosystem.

Discussions are, of necessity, occasionally of a technical nature and fall into five main catagories:

1. Sediments
2. Water Quality
3. Marsh Habitat
4. Benthic Communities
5. Fishery Resources

Data which have been collected along the proposed pipeline route as part of the scientific investigations of this project are discussed under the heading of "Pipeline Route".

2.2 Sediments

2.2.1 Background Information

2.2.1.1 Physical Characteristics

Roberts Bank between the coal port causeway and South Arm of the Fraser River consists of ca. 6,853 ha of intertidal flats which slope gently for about 7 km from the dyked land to the top of the foreslope. Sediments have been deposited on the delta platform over the past 8,000 years to its present average thickness of 110 m (Mathew and Shepard, 1962). Between 12 and 30 million tons of sediment are transported annually by the Fraser River, much of it comprised of sand. Milliman (1980) attributes the dominance of sand in the Fraser to the close proximity of mountains, the undammed nature of the river, and the marked seasonality in river flow.

The nature of surficial sediments along most of the intertidal flats of Roberts Bank was mapped by Medley and Luternauer (1976) who identified three basic surficial sedimentary domains. Domain 1 (sands) which commonly display some form of hydrodynamic structure such as current and wave ripples with wavelengths from a few centimetres to as much as 50 to 100 m (megaripples). Domain 2 (muds) are generally found on the upper tidal flats adjacent to marshes, in troughs between major megaripples and sand banks or are found adjacent to major tide channels. These relatively impermeable domain sediments are also commonly characterized by dendritic patterns of permanently water-filled drainage channels. Domain 3 (sandy silts) are transitional sediments generally occurring between the other two sedimentary environments. Since this sediment is relatively more permeable, drainage channels are generally water-free, elongate, narrow features either oriented towards the waterline or issuing from some form of permanent tidal creek.

In the vicinity of Canoe Pass, surface sediments are described as being typically coarser since the pass is a source of medium sand during freshet (Luternauer and Murray, 1973). Sediment size patterns on Roberts Bank also show seasonal variations as described by WCHL (1980). Major changes were noted during early freshet (April) when increasing supplies of silt-clay fractions became apparent downstream of Canoe Pass and Albion Channel. Finer sediments became more widespread as freshet proceeded through May. Grain size coarsened throughout the banks near the height of freshet in June but the maximum average diameter was not reached until the winter season.

2.2.1.2 Trace Metals

Details on the sediment chemistry of Roberts Bank have originated mainly from trace metal studies by Fletcher (1976)[1], and Hall (unpubl. data) as well as dredge spoil analyses by B. C. Research (1976a, 1977a), (Table 2.2-1 and Figure 2.2-1). According to Stancil (1980) trace metal concentrations in Roberts Bank sediment are generally similar to those found in other unpolluted locations of the Fraser estuary. The only exception to this are some localized samples from Roberts Bank which were occasionally lower in lead and zinc.

Table 2.2-1 shows trace metal levels measured in Steveston fishing harbour and near Iona sewage streatment plant (STP) effluent outfall to give an example of contaminated sediment from urban-industrial pollution. Sediments near the Iona STP outfall are heavily polluted with Cu, Pb, Zn, and Hg. These heavy metals are contained in the sewage effluent which is actually a mixture of domestic and industrial wastewater receiving only primary treatment (Koch et al., 1977). Fine organic sediments dominating the area around the outfall tend to trap and concentrate much of the heavy metal load originating from the STP (B. C. Research, 1975a).

In Steveston fishing harbour trace metal pollution probably originates from the upstream operation of two sewage treatment plants along Cannery Channel, as well as from antifouling paints (Dobrocky Seatech Ltd., 1980). Trace metal concentrations are slightly above average "base-line" values measured along Roberts Bank by Fletcher (1976) particularly for Cu, Pb, and Zn. As in other polluted sites of the Fraser, trace metal concentrations observed in sediments were strongly influenced by grain size distribution and organic content. Finer and more organic sediments usually contained the highest trace metal concentrations.

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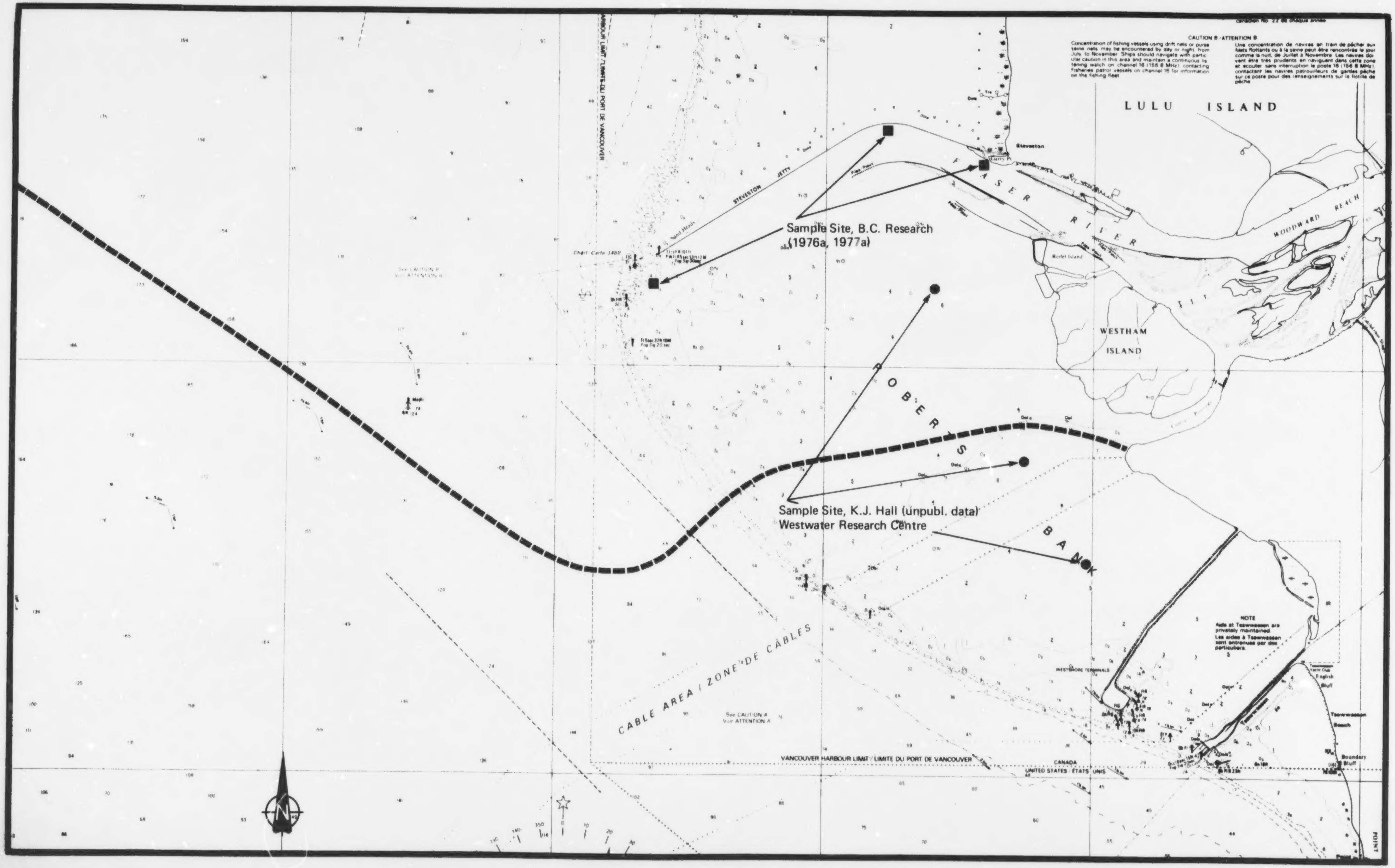
[1] Exact locations of the numerous sample stations on Roberts Bank are shown in Grieve and Fletcher (1976).


LULU ISLAND
Steveston
STEVESTON JETTY
Sand Heads
FRASER RIVER
WOODWARD REACH
Reifel Island
WESTHAM ISLAND
ROBERTS BANK
Sample Site, B.C. Research (1976a, 1977a)
Sample Site, K.J. Hall (unpubl. data) Westwater Research Centre
HARBOUR LIMIT / LIMITE DU PORT DE VANCOUVER
Chart Carte 3488
See CAUTION B Voir ATTENTION B
CABLE AREA / ZONE DE CABLES
See CAUTION A Voir ATTENTION A
VANCOUVER HARBOUR LIMIT / LIMITE DU PORT DE VANCOUVER
CANADA
UNITED STATES / ETATS UNIS
WESTSHORE TERMINALS
English Bluff
Tsawwassen Beach
Boundary Bluff
POINT
N

CAUTION B · ATTENTION B

Concentration of fishing vessels using drift nets or purse seine nets may be encountered by day or night from July to November. Ships should navigate with particular caution in this area and maintain a continuous listening watch on channel 16 (156.8 MHz) contacting Fisheries patrol vessels on channel 16 for information on the fishing fleet.

Une concentration de navires en train de pêcher aux filets flottants ou à la seine peut être rencontrée le jour comme la nuit, de Juillet à Novembre. Les navires doivent être très prudents en naviguant dans cette zone et écouter sans interruption le poste 16 (156.8 MHz), contactant les navires patrouilleurs de gardes pêche sur ce poste pour des renseignements sur la flotille de pêche.

NOTE
Aids at Tsawwassen are privately maintained.
Les aides à Tsawwassen sont entretenues par des particuliers.

Figure

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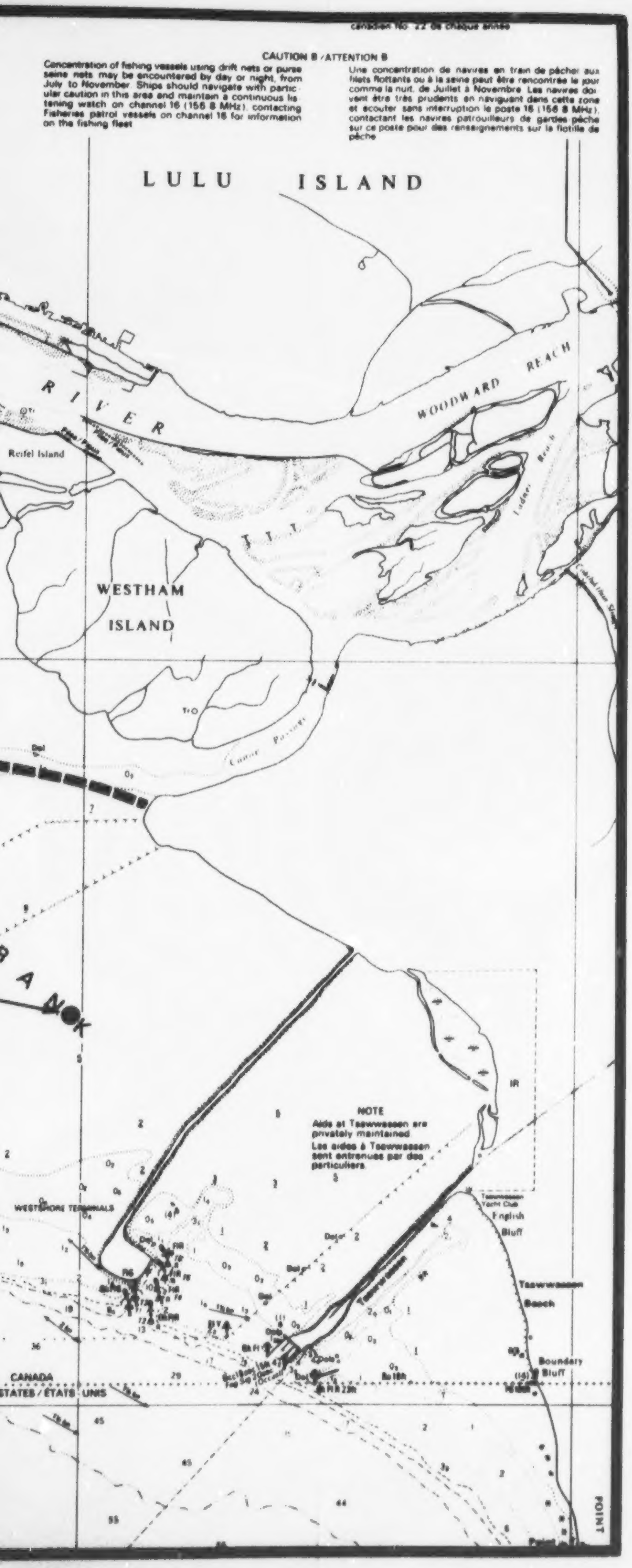

canadien No 22 de chaque année
CAUTION B / ATTENTION B
Concentration of fishing vessels using drift nets or purse seine nets may be encountered by day or night, from July to November. Ships should navigate with particular caution in this area and maintain a continuous listening watch on channel 16 (156 8 MHz), contacting Fisheries patrol vessels on channel 16 for information on the fishing fleet
Une concentration de navires en train de pêcher aux filets flottants ou à la seine peut être rencontrée le jour comme la nuit, de Juillet à Novembre. Les navires doivent être très prudents en naviguant dans cette zone et écouter sans interruption le poste 16 (156 8 MHz), contactant les navires patrouilleurs de gardes pêche sur ce poste pour des renseignements sur la flotille de pêche
LULU ISLAND
RIVER
WOODWARD REACH
Reifel Island
Ladner Reach
WESTHAM ISLAND
Canoe Passage
NOTE
Aids at Tsawwassen are privately maintained
Les aides à Tsawwassen sont entretenues par des particuliers
WESTSHORE TERMINALS
Tsawwassen Yacht Club
English Bluff
Tsawwassen Beach
Boundary Bluff
CANADA
STATES / ÉTATS UNIS
POINT

Figure 2.2-1

Locations showing where some of the more detailed geochemical investigations have been conducted prior to this study. Numerous sampling sites of Grieve and Fletcher (1976) are not shown.

▬ Proposed Pipeline Route

● ■ Sample Sites

0 1 2 3 4km

0 1 2 Miles

Scale 1:75,000

Table 2.2-1 Trace metal values of sediments from various polluted and unpolluted locations in the Fraser estuary.

Location	% Volatile	% C.O.D.	ppm TKN	ppm TP	ppm Sulfides	% Organic C
North Arm Fraser R. (Morrison et al., 1975)	0.49-5.28	0.28-19.9	90-720	214-880	L 5-366	-
Sturgeon Bank (Morrison et al., 1975)	-	5.1-6.2	-	-	-	-
Near Iona Outfall (B.C. Research, 1975a)	-	-	6185	2028	-	6.06
Polluted Harbour Bottom (O'Neal & Sceva, 1971)	10.2-49.3	3.9-39.5	580-6800	590-2550	100-3770	-
Unpolluted Harbour Bottom (O'Neal & Sceva, 1971)	0.7-5.0	3-48	100-1310	240-950	30-510	-

Total sulfides measured by acid reflux
L = less than
C.O.D. = Chemical Oxygen Demand
TKN = Total Kjeldahl Nitrogen
TP = Total Phosphorus

An inverse relationship between trace metal content and sand content of the sediments was clearly shown by Grieve and Fletcher's (1976) extensive geochemical survey of the Fraser delta. A further strong positive correlation was also found between Fe and Mn and other heavy metals such as Co, Cu, Pb, and Zn, suggesting a scavenging of trace metals by hydrous oxides of Fe and Mn. Therefore, physical processes causing local accumulations of heavy minerals can also result in greater trace metal concentrations in spite of the presence of coarser grain sizes.

Another important aspect of heavy metal geochemistry relates to their partitioning within the sediments. Grieve and Fletcher's (1976) results indicate that concentrations of exchangeable metal (readily available) are negligible compared to hydrous oxide and lattice-bound forms. An exception to this partitioning pattern occurs in the vicinity of the Iona sewage outfall where natural geochemical processes are strongly influenced by the high trace metal levels associated with wastewaters.

2.2.1.3 Other Chemical Elements and Compounds

Geochemical information about Roberts Bank sediment, other than trace metals, is almost non-existent. The main area of attention has been Sturgeon Bank, in particular the Sea Island tidal flats. Geochemical work done in conjunction with the proposed Vancouver International Airport (VIA) expansion (Morrison et al., 1975; Pollutech, 1974) and Iona Island sewage outfall (e.g. B. C. Research, 1975a) are the best sources available on chemical information pertaining to deltaic sediment of the Fraser.

Table 2.2-2 compiles analytical results of surface samples for various locations on Sturgeon Bank as well as "typical" bottom material from Pacific Northwest harbour areas. In order to gain some perspective on the significance of these data, a representative range of conditions for natural and polluted locations is provided.

The Environmental Protection Service (EPS) carried out analyses on toxic organic contaminant residue levels on Sturgeon Bank sediment several kilometres seaward of Sea Island dyke and away from the influence of Iona STP and found no organic

Table 2.2-2 Chemical characteristics of sediments from polluted and unpolluted locations in the Fraser estuary and in typical Pacific northwest harbour areas.

Location	% Volatile	Co	Cu	Fe*	Mn	Ni	Pb	Zn	Hg	Cd	Cr
Mean Value For Roberts Bank (Fletcher, 1976)	-	11.53	24.77	23.49	289	45	2.90	54.13	-	-	-
Steveston Jetty (B.C. Research, 1977a)	.09-1.30	-	17.1-18.3	20.5-28.9	-	31.6-54.1	3.7-12.9	38.2-44.7	0.02-0.04	L 0.5	34.5-68.2
Steveston Harbour (B.C. Research, 1976a)	4.5	15.0	44.0	35.0	440	43.5	14.0	84.0	0.12	L 0.4	61.2
Near Iona Outfall (Stancil, 1980)	-	14.0	209	28.3	289	42	186	246	1.22	3.7	-

* $(X10^3)$
L = less than
Values reported as total metals in ppm dry weight measured by atomic absorption spectrophotometry

chlorines nor polychlorinated byphenyls (PCBs) above detection limits (Morrison et al., 1975). On the other hand, sediment samples collected near Iona Island sewage outfall as part of the Department of Environment (DOE) study on organic contaminants in the estuary region contained 214 ppb PCB as well as equally significant levels of phthalate esters and lower concentrations of 1,2-dichlorobenzene and naphthalene (Garrett, 1980). Most stations in the Fraser estuary sampled at some distance away from pollution sources (sewage outfalls, landfill leachates, ocean dumping areas) contained organic contaminant levels in sediments below levels of detection.

2.2.1.4 Vertical Gradients

Several bore hole samples taken in the North Arm for environmental impact studies of the proposed VIA expansion provide some of the few data available on vertical chemical gradients in Fraser estuary sediment (Pollutech, 1974). Since only three bore holes of 6 m depth were taken, it is difficult to interpret any patterns or statistical significance from the data. Volatile content showed maximum values in one surface sample (0 to 0.46 m) and two bottom samples (6 to 6.6 m). Chemical Oxygen Demand (COD), sulfides, and total P values showed similar variabilities. Lead was the only metal that showed a peculiar peak (>100 ppm) in deeper levels.

The only vertical sediment data of Roberts Bank were from the 1 m deep coring tube samples taken by Westwater in 1973 (Hall, unpubl. data) and recent deep bore hole samples from studies related to the coal port expansion project. Hall's data show relatively distinct patterns of vertical gradients in only some locations and for only certain metals. The most pronounced vertical concentration gradient was evident for Pb in two of three locations sampled. That is, concentrations decreased from values of approximately 4 ppm on the surface to zero in deeper samples. A smaller gradient was evident for Zn, Fe, and Cu in only some locations. Vertical concentration gradients for most other metals and locations were rather indistinct suggesting that the tidal flat sediments are generally well mixed as a result of biophysical processes.

Deep (18 m) sediment samples have been taken near the coal port causeway borrow pit area by the NHB, Port of Vancouver (unpubl. data). With the exception of the rather high Pb levels, trace metal values are similar to those measured by Hall in shallower sediment samples from Roberts Bank.

2.2.2 Pipeline Route

B. C. Hydro collected soil samples for geochemical reasons along the pipeline route. Samples were obtained in autumn of 1980 at ca. 15 bore hole stations along the entire length of the pipeline route. Maximum depths of samples were between 7 and 9 m with samples being taken at approximately 60 cm depth increments. Results of this geotechnical work are described in a report by Monenco (1981).

A selection of samples were retained from deeper sediments (1 to 8 m) of various bore hole stations of the geotechnical survey (Figure 2.2-2). Only trace metals (As, Hg, Cd, Pb, Zn, Fe, Mn, Co) were measured in these samples because of their previous length of storage. Therefore, additional grab samples were taken on 28 April 1981 with a Van Veen grab and on 6 May 1981 with hand-driven coring tubes (1 m long, 7 cm diameter). Exact locations of sample stations are shown in Figure 2.2-2. These samples were acquired because parameters such as organic matter, COD, nutrients, sulfides, and organohalogens change considerably with time and storage and can therefore only be measured accurately in fresh samples.

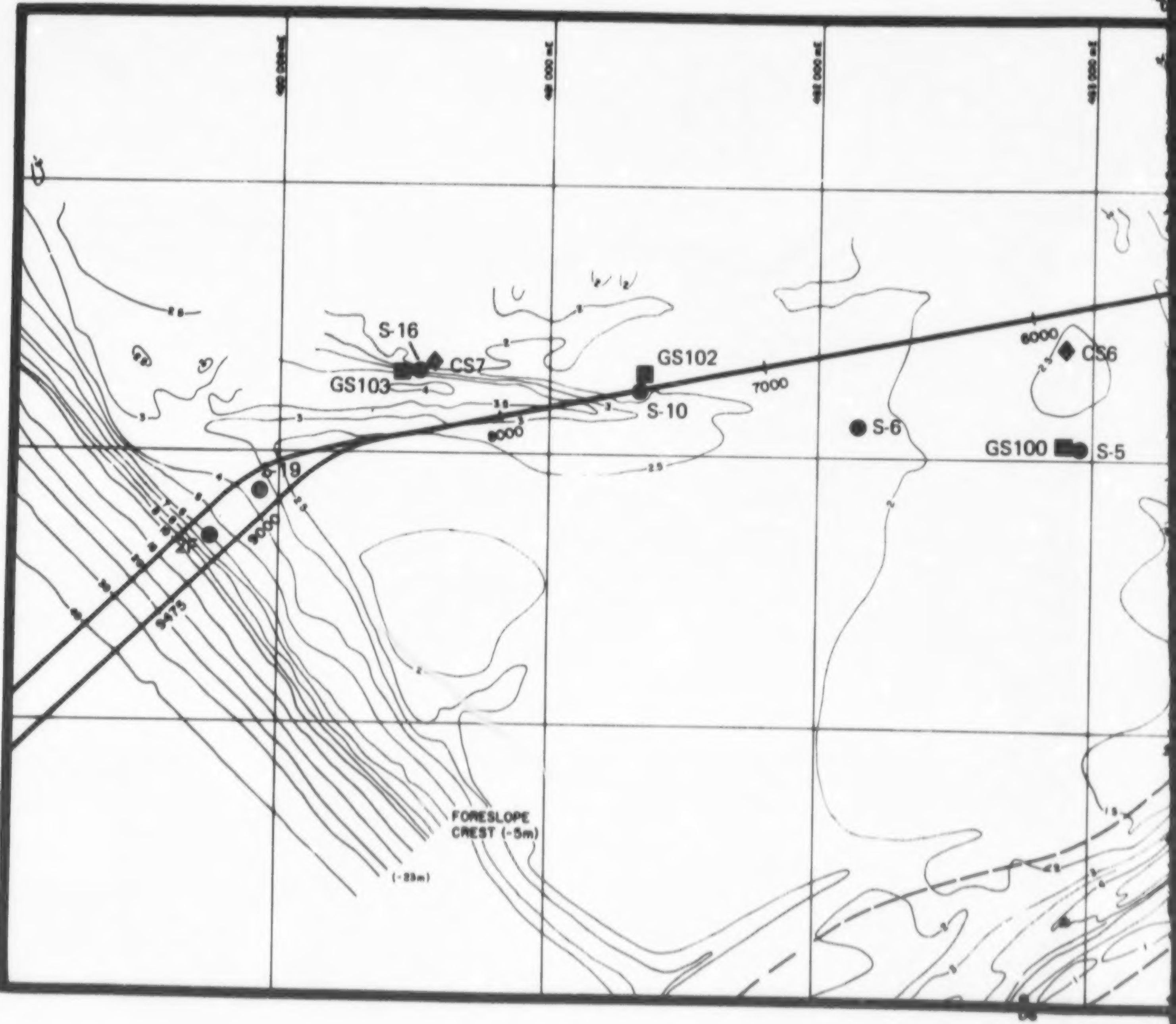
Grab samples were stored in 1 L acid washed glass jars and delivered on the same day to Can Test Ltd. for analyses. Core samples were delivered intact, tightly sealed inside the plastic coring tubes. Details of laboratory procedures and quality control are given in Appendix 6.2.

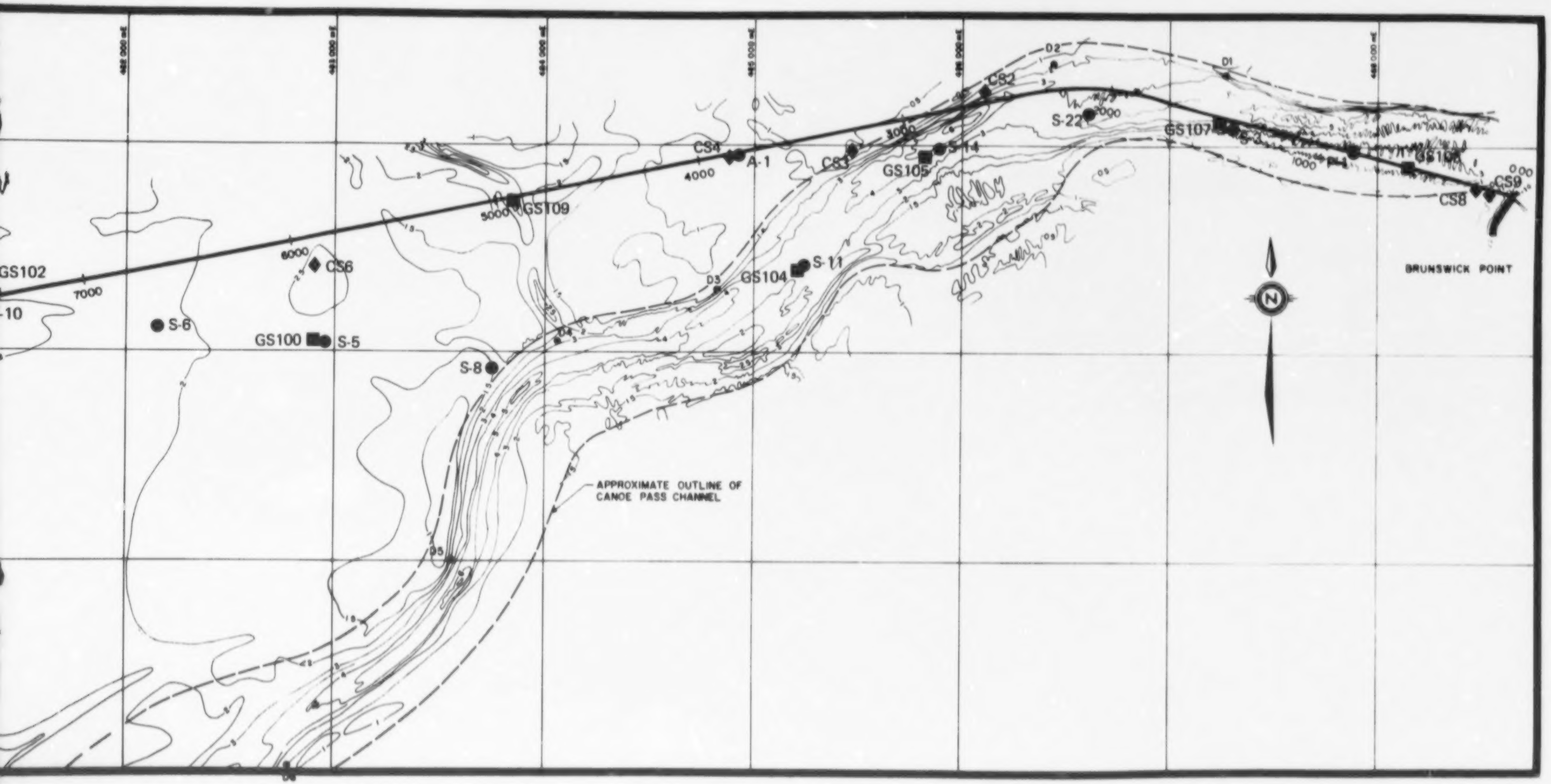
2.2.2.1 Physical Characteristics

Along most of the route, grain size distribution of the top 1 m of sediment is typically medium to fine sand (2 mm to 63 μ) with less than 10% silt (63 to 4μ) and less than 5% clay (<4μ) fractions (Table 2.2-3). Exceptions to the commonly found grain size pattern were found in the marsh/mudflat environment where silt-clay fractions were much greater than anywhere else. Two stations in Canoe Pass also showed a greater occurrence of silt fractions particularly near a

LEGEND Legend for Figure 2.2-2 and Tables 2.2-3, 2.2-4, 2.2-5, 2.2-6, and 2.2-7.

Sample Number	Field Code	Classification	Average Depth (m)	Distance From Dyke (km)
		MARSH/MUDFLAT		
1	CS9	core (total)	0.14	0.15
2	CS8	core (total)	0.29	0.20
		RIVERINE		
3	GS108	grab	0	0.5
3-1	P-1	borehole	6.1	0.8
3-2	S3-1	borehole	2.1	1.4
3-3	S3-2	borehole	4.6	1.4
4	GS107	grab	0	1.5
4-1	S22-1	borehole	1.5	2.0
4-2	S22-2	borehole	4.6	2.0
4-3	S22-3	borehole	7.3	2.0
5	CS2	core (top)	0	2.6
6	CS2	core (bottom)	0.71	2.6
6-1	S14	borehole	6.7	2.8
7	GS105	grab	0	2.9
8	GS104	grab	0	3.5
8-1	S11	borehole	2.7	3.5
		INTERTIDAL SANDFLAT		
9	CS3	core (top)	0	3.2
10	CS3	core (bottom)	0.71	3.2
10-1	A1-1	borehole	3.8	3.2
10-2	A1-2	borehole	7.3	3.2
11	CS4	core (top)	0	3.8
12	CS4	core (middle)	0.33	3.8
13	CS4	core (bottom)	0.66	3.8
		INTERTIDAL SANDFLAT (cont'd.)		
14	GS109	grab	0	4.8
14-1	S8-1	borehole	2.4	5.0
14-2	S8-2	borehole	4.0	5.0
15	GS100	grab	0	5.8
15-1	S5-1	borehole	4.0	5.8
15-2	S5-2	borehole	6.4	5.8
16	CS6	core (top)	0	5.8
17	CS6	core (bottom)	0.68	5.8
17-1	S6-1	borehole	2.1	6.4
17-2	S6-2	borehole	4.0	6.4
18	GS102	grab	0	7.3
18-1	S10-1	borehole	2.7	7.3
18-2	S10-2	borehole	4.7	7.3
18-3	S10-3	borehole	8.1	7.3
19	CS7	core (top)	0	8.1
20	CS7	core (bottom)	0.66	8.1
20-1	S16-1	borehole	1.5	8.1
20-2	S16-2	borehole	2.7	8.1
20-3	S16-3	borehole	7.6	8.1
		DELTA FORESLOPE		
21	GS103	grab	0	8.2
21-1	S19	borehole	7.0	9.0
22-1	2F-1	borehole	4.9	9.2
22-2	SF-2	borehole	3.4	9.2

S-16
CS7
GS103
GS102
S-10
7000
8000
S-6
GS100
S-5
6000
CS6
S-19
9000
9475
FORESLOPE
CREST (-5m)
(-20m)



482 000 mE
483 000 mE
484 000 mE
485 000 mE
486 000 mE
488 000 mE
D2
D1
CS2
S-22
2000
GS107
S-2
1000
GS108
CS9
CS8
CS4
A-1
4000
CS3
3000
GS105
S-14
5000
GS109
6000
CS6
GS102
7000
-10
S-6
GS100
S-5
GS104
S-11
D3
D4
S-8
D5
D6
APPROXIMATE OUTLINE OF CANOE PASS CHANNEL
BRUNSWICK POINT
N

Figure 2.2-2

Location and identification of sediment samples taken along the proposed pipeline route.
(See also LEGEND on facing page)

● Borehole (0 to <8m depth)

■ Surface grab

◆ Coring tube (0 to <1m depth)

0 .5 1km

Horizontal Scale 1:20,000

Table 2.2-3 Geochemical data of pipeline route sediments, <1 m depth: Physical characteristics.

Habitat Zone	Sample Number	pH	% Moisture	% Volatile	% Particle Size Distribution 2mm	2mm-63μm	63-4μm	4μm
Marsh Mudflat	1	7.30	33.1	5.63	0	14.9	67.4	17.7
	2	7.40	34.1	5.69	0	20.2	65.7	14.1
	Mean	7.35	33.6	5.66	0	17.5	66.5	15.9
Riverine	3	7.45	21.9	2.5	0	83.7	11.9	4.4
	4	7.45	20.6	2.2	0	96.9	1.4	1.7
	5	7.65	21.7	1.80	0	97.8	0.5	1.7
	6	7.75	23.4	2.70	0	88.1	9.5	2.4
	7	7.25	24.1	3.5	0	73.8	20.2	6.0
	8	7.35	18.6	4.0	0	98.5	0.2	1.3
	Mean	7.48	21.7	2.78	0	89.8	7.28	2.91
	Range	7.25-7.65	18.6-24.1	1.8-4.0	0	73.8-98.5	0.2-20.2	1.3-6.0
Intertidal Sandflats	9	7.70	23.3	2.00	0	97.7	0.4	1.9
	10	7.80	24.0	2.23	0	95.4	2.1	2.5
	11	7.80	23.0	2.14	0	95.2	2.5	2.3
	12	7.80	24.3	3.51	0	88.0	5.7	6.3
	13	7.80	22.9	2.06	0	96.1	1.4	2.5
	14	7.60	22.9	2.6	0	91.2	6.0	2.8
	15	7.60	23.3	2.4	0	97.6	0.7	1.7
	16	7.75	23.9	2.50	0	85.9	9.3	4.8
	17	7.40	22.3	1.83	0	98.0	0.1	1.9
	18	7.20	23.3	2.4	0	97.1	0.2	2.7
	19	7.50	22.7	1.83	0	98.0	0.1	1.9
	20	7.70	21.7	2.26	0	96.9	0.7	2.4
	Mean	7.63	23.1	2.31	0	94.7	2.43	2.80
	Range	7.20-7.80	21.7-24.3	1.83-3.51	0	88.0-98.0	0.1-9.3	1.9-6.3
Delta Foreslope	21	7.3	23.0	4.1	0	96.8	0.9	2.3

scour hole and what may have been other back-eddy or dead-water locations. Deeper sediments (1 to 7 m) examined from borehole samples showed a common grain size pattern either classified as fine sand or silty sand. Samples taken on the upper foreslope were classified as sandy silt (Monenco, 1981).

Volatile components of sediments along the pipeline route averaged around 2.5% with only the marsh/mudflat and foreslope-subtidal environments approaching values around 5.0%. Levels below approximately 5 to 10% can be considered normal background values not excessively loaded with organics.

2.2.2.2 Nutrients and COD

Concentrations of nutrients, carbon and the COD in sediments of the marsh/mudflat zone were highest of all locations sampled (Table 2.2-4). This is to be expected due to the greater biological productivity and finer sediments found in this zone. For the same reasons, and also because of the greater occurrence of anaerobic soils, levels of soluble sulfides in the marsh were between 2 and 10 times greater than in other locations. Nutrient levels, total carbon, soluble sulfide and the COD of sediments in Canoe Pass and across the intertidal sandflats were relatively low. Mean values for these environments, shown in Table 2.2-4, are generally below levels measured in sediments of the North Arm and Sturgeon Banks (Table 2.2-2).

2.2.2.3 Organohalogens

Concentrations of DDT and its derivatives were below levels of detection for every sampling site. Concentrations of Pentachlorophenol (PCP), although detectable in a few locations, (Table 2.2-5), were generally well below levels recorded for sediments closer to forest industry effluent sources in the lower Fraser River and estuary. Levels of PCP reported by Garret (1980) for Fraser River sediments contaminated by forest industry effluents range from 0.01 to 0.09 ppm with heavily polluted sediments containing up to 525 ppm.

Levels of polychlorinated byphenyl (PCB) in sediments sampled along the pipeline route were generally below detectable levels or fluctuated within a range of values expected for Fraser estuary sediments (Table 2.2-5). Expected values for

Table 2.2-4 Geochemical data of pipeline route sediments, <1 m depth: Nutrients and COD.

Habitat Zone	Sample Number	C.O.D.	ppm TN	ppm TKN	% TC	ppm Sol.S	ppm P-PO$_4$
Marsh Mudflat	1	2.84	810	750	1.34	3.52	786
	2	2.59	720	670	1.30	1.40	789
	Mean	2.71	765	710	1.32	2.46	786
Riverine	3	0.71	170	160	0.33	4.04	388
	4	0.38	80	100	0.14	L 1.0	359
	5	0.36	130	140	0.15	0.28	483
	6	0.57	300	160	0.31	0.26	532
	7	1.22	280	280	0.45	L 1.0	424
	8	0.25	80	80	0.12	L 1.0	312
	Mean	0.58	173	153	0.25	1.26	416
	Range	0.36-1.22	80-300	80-280	0.12-0.45	0.26-4.04	359-532
Inter-tidal Sand-flats	9	0.31	200	170	0.17	L 0.10	470
	10	0.40	180	130	0.22	0.14	473
	11	0.41	150	160	0.21	L 0.10	532
	12	1.00	290	190	0.47	0.70	685
	13	0.30	160	100	0.13	L 0.10	499
	14	0.59	160	170	0.31	L 0.10	398
	15	0.28	100	110	0.14	L 1.0	496
	16	0.31	120	120	0.18	L 0.10	489
	17	0.44	360	160	0.27	0.22	561
	18	0.29	160	120	0.16	L 1.0	486
	19	0.26	140	140	0.14	L 0.10	492
	20	0.31	140	110	0.14	0.40	483
	Mean	0.41	180	140	0.21	0.34	505
	Range	0.26-1.00	100-360	100-190	0.13-0.47	0.10-1.0	398-685
Delta Fore-slope	21	0.33	180	170	0.19	L 1.0	466

C.O.D. = Chemical Oxygen Demand
TN = Total Nitrogen
TKN = Total Kjeldahl Nitrogen
TC = Total Carbon
Sol.S = Soluble Sulphide
TP = Total Phosphorus
L = Less than

Table 2.2-5 Geochemical data of pipeline route sediments, <1 m depth: Organoholagens.

Habitat Zone	Sample Number	DDT	DDD	DDE	PCB	PCP
Marsh Mudflat	1		ND		0.017(b)	L 0.005
	2				0.025(b)	L 0.005
	Mean		-		0.021	L 0.005
Riverine	3		ND		L 0.005	0.006
	4				-	-
	5				-	-
	6				-	-
	7				L 0.005	L 0.005
	8				0.013(a)	0.028
	Mean		-		0.008	0.013
	Range		-		0.005-0.013	0.005-0.028
Intertidal Sandflats	9		ND		L 0.005	0.007
	10				L 0.005	L 0.005
	11				-	-
	12				-	-
	13				-	-
	14				L 0.005	0.005
	15				L 0.005	0.016
	16				L 0.005	L 0.005
	17				L 0.005	L 0.005
	18				-	-
	19				L 0.005	0.005
	20				0.019(b)	L 0.005
	Mean		-		0.007	0.007
	Range		-		0.005-0.019	0.005-0.016
Delta Foreslope	21		ND		0.88(a)	0.006

Results expressed as micrograms per gram dry weight of sediment
ND = Not detected = L 0.001 ppm
L = Less than
(a) = Arochlor 1248
(b) = Arochlor 1260

PCB levels in the Fraser Estuary are based on levels reported by Garrett (1980) as EPS data for sites in the North and Main Arms having concentrations of 0.010 to 0.050 ppm, dry weight. Also as expected, the higher silt-clay and organic matter contents of the marsh/mudflat environment would tend to increase sediment adsorption and binding capacity resulting in PCB levels higher than values measured across the remaining portion of the route.

Sediment collected on the foreslope (Station GS 103; Figure 2.2-2) contained a relatively high level of PCB (Table 2.2-5). From PCB levels in sediment measured at various polluted locations in the lower Fraser River, concentrations greater than approximately 0.50 ppm. and up to 1.00 ppm can be considered moderately polluted (Hall et al., 1976; Garrett, 1980). Until further tests are made of sediments at and around Station GS 103, it is difficult to comment further on the significance of this one high result.

2.2.2.4 Trace Metals

Sediment concentrations of Cu, Fe, Mn, Pb, and Zn for samples taken in the riverine, intertidal and subtidal environments (Table 2.2-6) are at or below mean values reported for Roberts Bank by Fletcher (1976) and Hall (Table 2.2-1). The same conclusion applies to the marsh/mudflat environment with the exception of Pb concentrations which tended to be between two to four times greater in average value. However, Pb concentrations up to 12.9 ppm have been measured in sediments near Steveston Jetty and polluted levels tend to be approximately an order of magnitude greater still (Table 2.2-1).

Mean values shown in Table 2.2-6 for toxic trace metals such as Hg and Cd fall within the range of values reported by B. C. Research (1977a) for Steveston Jetty area sediments and by Morrison et al. (1975) for North Arm sediments. These values can be considered typical of unpolluted sediments in the Fraser estuary. However, Station GS 100 (Figure 2.2-2) sampled along the pipeline route showed a Cd concentration of 1.03 ppm. Although this concentration is only an isolated peak, it nevertheless comes close to the category of slightly polluted sediment according to results compiled by Stancil (1980). Concentrations of Cd in polluted sediments close to Iona outfall range between 1.4 and 5.8 ppm. Mean concentrations in various backwater sediments of industrialized

Table 2.2-6 Geochemical data of pipeline route sediments, <1 m depth: Trace metals.

Habitat Zone	Sample Number	Hg	Cd	Pb	As	Cu	Zn	Mn	($X10^3$) Fe
Marsh Mudflat	1	0.059	0.18	14.0	11.4	35.7	69.7	309	13.6
	2	0.056	0.20	8.0	7.44	33.3	65.2	349	19.5
	Mean	0.0575	0.19	11.0	9.42	34.5	67.5	329	16.55
Riverine	3	0.031	0.12	2.2	4.91	13.8	42.1	250	14.8
	4	0.018	0.49	1.9	4.13	12.2	35.7	297	13.5
	5	0.012	L 0.06	2.5	3.23	13.2	40.6	306	19.8
	6	0.038	0.10	2.9	9.20	20.5	44.9	319	19.2
	7	0.057	0.25	3.9	5.66	17.2	47.2	293	15.0
	8	0.012	0.29	2.1	3.00	8.57	29.9	283	12.0
	Mean	0.028	0.22	2.6	5.02	14.2	40.1	291	15.7
	Range	0.12-0.057	0.06 0.49	1.9-3.9	3.0-9.2	12.2-20.5	29.9-47.2	250-319	12.0-19.8
Inter-tidal Sand-flats	9	0.024	L 0.06	2.8	3.83	13.0	37.7	338	15.7
	10	0.022	L 0.06	3.0	4.36	14.4	40.5	264	16.9
	11	0.025	L 0.06	4.1	4.48	13.8	39.0	374	16.5
	12	0.064	L 0.06	5.6	15.6	24.6	54.5	357	16.8
	13	0.056	L 0.06	3.1	4.26	11.7	36.5	251	16.9
	14	0.033	0.78	1.9	4.89	12.8	41.6	271	14.1
	15	0.028	1.03	2.6	5.32	9.96	34.8	418	16.3
	16	0.025	L 0.06	3.6	5.14	12.2	38.0	444	16.2
	17	0.047	L 0.06	3.5	6.10	16.2	42.0	343	15.7
	18	0.022	0.35	2.1	4.94	10.3	34.7	353	15.6
	19	0.021	L 0.06	3.1	4.64	11.7	36.4	402	15.3
	20	0.023	L 0.06	3.1	4.62	11.2	36.8	394	15.7
	Mean	0.0325	0.225	3.2	5.68	13.5	39.4	351	16.0
	Range	0.021-0.064	0.06-1.03	2.1-5.6	3.83-15.6	10.3-16.2	34.7-54.5	251-444	14.1-16.9
Delta Fore-slope	21	0.052	0.63	3.1	5.27	12.3	43.6	348	12.9

Results expressed as micrograms element per dry gram of sediment.
L = Less than

locations of the Fraser River range between 1.4 and 4.0 ppm. Cadmium measured in sediments upstream of Canoe Pass by B. C. Research (1973) showed a value of 0.70 ppm.

Arsenic concentrations along the proposed pipeline route are also considered to be in the range of uncontaminated sediments. Crecelius et al. (1975) conducted a detailed study of selected trace metals in Puget Sound and reported arsenic levels between 4 and 15 ppm dry weight in unpolluted areas while areas contaminated by the smelter in Tacoma, Washington had arsenic levels as high as 10,000 ppm.

Trace metal concentrations of 25 sediment samples taken from an average depth of 4.5 m at borehole stations along the pipeline route are shown in Table 2.2-7. Non-statistical comparisons of the data with those of surface samples (Table 2.2-6) suggest that concentrations of Pb, Zn, Mn, As, and P are generally similar at all locations and depths. Average levels of Fe and Cu in deep foreslope sites were twice those found near the surface. Cd values were considerably less, and Hg levels greater in deeper compared to surface samples. However, as with the previously discussed trace metal data of the pipeline route, values measured in the borehole samples fall within the general range of baseline values reported in the literature for uncontaminated Fraser estuary sediments.

Table 2.2-7 Geochemical data of pipeline route sediments, 1 to 8 m depth: Physical characteristics and trace metals (1)

Habitat Zone	Sample Number	% Clay	% Silt	% Sand	% Organic	% Sulphate	Hg	Cd	Pb	Zn	(X10^3) Fe	Mn	Cu	As	P
Riverine	3-1	-	-	-	-	-	0.15	0.05	2.6	36.0	19.0	356	10.0	3.1	456
	3-2	-	-	-	0.3	0.03	0.37	0.05	2.4	35.2	18.7	350	11.5	4.0	466
	3-3	0.0	6.0	9.5	-	-	0.10	0.05	2.5	38.5	17.9	314	11.5	2.6	447
	4-1	5.0	40.0	55.0	-	-	0.08	0.05	6.2	63.4	28.0	360	24.5	8.5	587
	4-2	2.0	10.0	88.0	-	-	0.05	0.05	4.7	82.6	26.8	377	18.8	4.9	515
	6-1	0.0	3.5	96.5	-	-	0.02	0.05	2.8	46.0	19.2	310	18.3	4.3	450
	8-1	0.0	6.0	94.0	-	-	0.01	0.05	3.6	45.3	19.0	313	16.0	4.8	461
	Mean (2)	2.3	23.3	74.6	0.3	0.03	0.11	0.05	3.98	49.6	22.3	360	17.8	4.5	508
	Range (2)	0.0-	3.5-	19.0-	-	-	0.01-	-	2.4-	35.2-	17.9-	313-	10-	2.6-	447-
		7.0	74.0	96.5			0.37		7.1	82.6	30.1	497	31.7	8.5	685
Inter-tidal Sand-flats	10-1						0.09	0.05	2.2	72.3	21.7	368	13.5	3.6	476
	10-2	0.0	1.0	99.0	-	-	0.02	0.05	2.0	94.8	21.6	333	11.5	3.2	460
	14-1	2.0	22.0	76.0	-	-	0.06	0.05	4.3	44.5	23.0	301	17.5	4.1	571
	14-2	2.5	31.5	66.0	-	-	0.07	0.05	3.8	47.5	26.3	381	21.5	5.1	593
	15-1	2.0	14.0	84.0	-	-	0.04	0.05	3.2	39.5	21.0	388	14.5	4.4	530
	15-2	0.0	2.0	98.0	-	-	0.05	0.05	2.7	33.0	18.8	357	14.5	4.2	434
	17-1	0.0	10.0	90.0	-	-	0.04	0.05	3.2	32.5	18.7	316	13.5	3.7	447
	17-2	0.0	12.0	88.0	-	-	0.05	0.24	3.7	42.7	20.5	342	17.6	5.3	438
	18-1	1.5	14.5	84.0	-	-	0.05	0.05	2.7	38.0	20.0	324	12.5	3.9	525
	18-2	2.5	31.5	66.0	2.7	0.02	0.02	0.05	3.6	91.8	25.5	389	20.1	5.0	567
	18-3	0.0	1.0	99.0	-	-	0.01	0.05	2.2	47.2	18.4	295	15.2	3.6	427
	20-1	2.5	26.0	71.5	-	-	0.05	0.05	3.5	52.6	24.3	376	19.1	6.0	564
	20-2	3.0	22.0	75.0	-	-	0.05	0.05	3.0	49.5	21.6	352	17.6	6.0	512
	20-3	0.0	7.0	93.0	-	-	0.07	0.05	5.8	60.5	27.1	460	28.4	7.0	605
	Mean	1.23	14.9	83.8	2.7	0.02	0.05	0.06	3.3	53.3	22.0	356	16.9	4.7	511
	Range	0.0-	1.0-	66.0-	-	-	0.01-	0.05-	2.0-	32.5-	18.7-	295-	11.5-	3.2-	427-
		3.0	31.5	98.0			0.09	0.24	5.8	94.8	27.1	460	28.4	7.0	605
Delta Fore-slope	21-1	0.0	0.0	100.0			0.04	0.05	2.3	42.8	17.4	289	16.1	3.8	408
	22-1	8.0	64.0	28.0	0.3		0.09	0.05	6.6	68.7	30.3	380	29.9	7.5	720
	22-2	4.0	44.0	52.0	0.0	0.0	0.12	0.05	6.4	68.1	28.9	397	31.1	6.5	649
	Mean	4.0	36.0	60.0	0.3	0.0	0.08	0.05	5.1	59.9	25.5	355	25.7	5.9	592

(1) All units expressed in µg per g dry weight of sediment sampled unless otherwise indicated.
(2) Includes sample No. 4-3 not shown in this table.

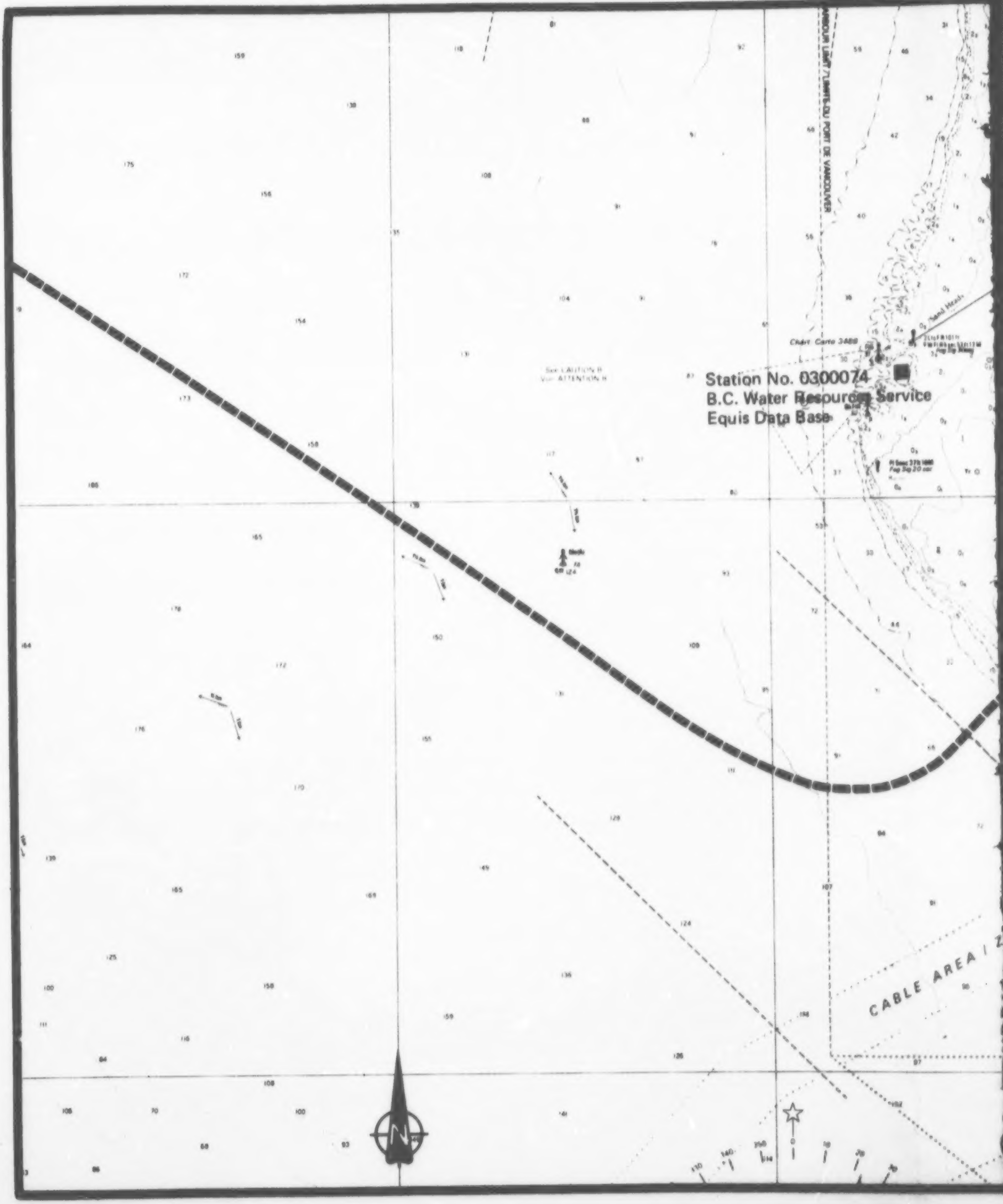
2.3 Water Quality

Only occasional water quality measurements have been made anywhere along the pipeline route. The only detailed spatial-temporal information available is related to salinity, conductivity, and temperature. Conductivity and temperature profiles taken on five occasions from July to October 1973 are available for a station 3 miles west of Canoe Pass (EQUIS Data Base). More recently, salinity profiles were made by Stonach and Crean (pers. comm.) along a cruise track down the central portion of Roberts Bank between the coal port causeway and Steveston Jetty. Temperature and salinity measurements have also been taken in residual surface water at low tide in conjunction with biological work on the exposed banks (e.g. Levings and Coustalin, 1975).

Stations closest to the pipeline route with comprehensive water quality data are situated north at Sand Heads, south near both causeways and at several upstream stations along the South Arm. These stations reflect a range of water quality conditions brought about by physical and biogeochemical estuarine processes.

Hydrological conditions are briefly described in the following section of this report on the basis of some recent work done in the study area. It is apparent that much of the remaining information on the hydrologic nature of the estuary is concerned with either river dynamics (e.g. Hodgins, 1974; WCHL, 1977) or oceanographic mechanisms associated with the Fraser River plume (e.g. Waldichuk, 1957; Stronach, 1977).

Existing water quality conditions will be described on the basis of comprehensive seasonal data available from stations at Sand Heads, Tsawwassen terminal and Woodward Island (Figure 2.3-1). These stations were chosen because of their proximity to the pipeline route, their remoteness from any point source pollution, and because they represent the typical ranges of salinity indicative of the type of mixed water mass circulating over the banks. Water measured at Woodward Island would be strongly river dominated whereas measurements taken at Tsawwassen terminal would show a stronger influence from Strait of Georgia water. Sand Heads water would tend to fluctuate between being either dominated by the river or the Strait of Georgia depending on river flow and tidal stage.


HARBOUR LIMIT / LIMITE DU PORT DE VANCOUVER
Chart Carte 3488
Sand Heads
See CAUTION B
Voir ATTENTION B
CABLE AREA / Z

Station No. 0300074
B.C. Water Resources Service
Equis Data Base

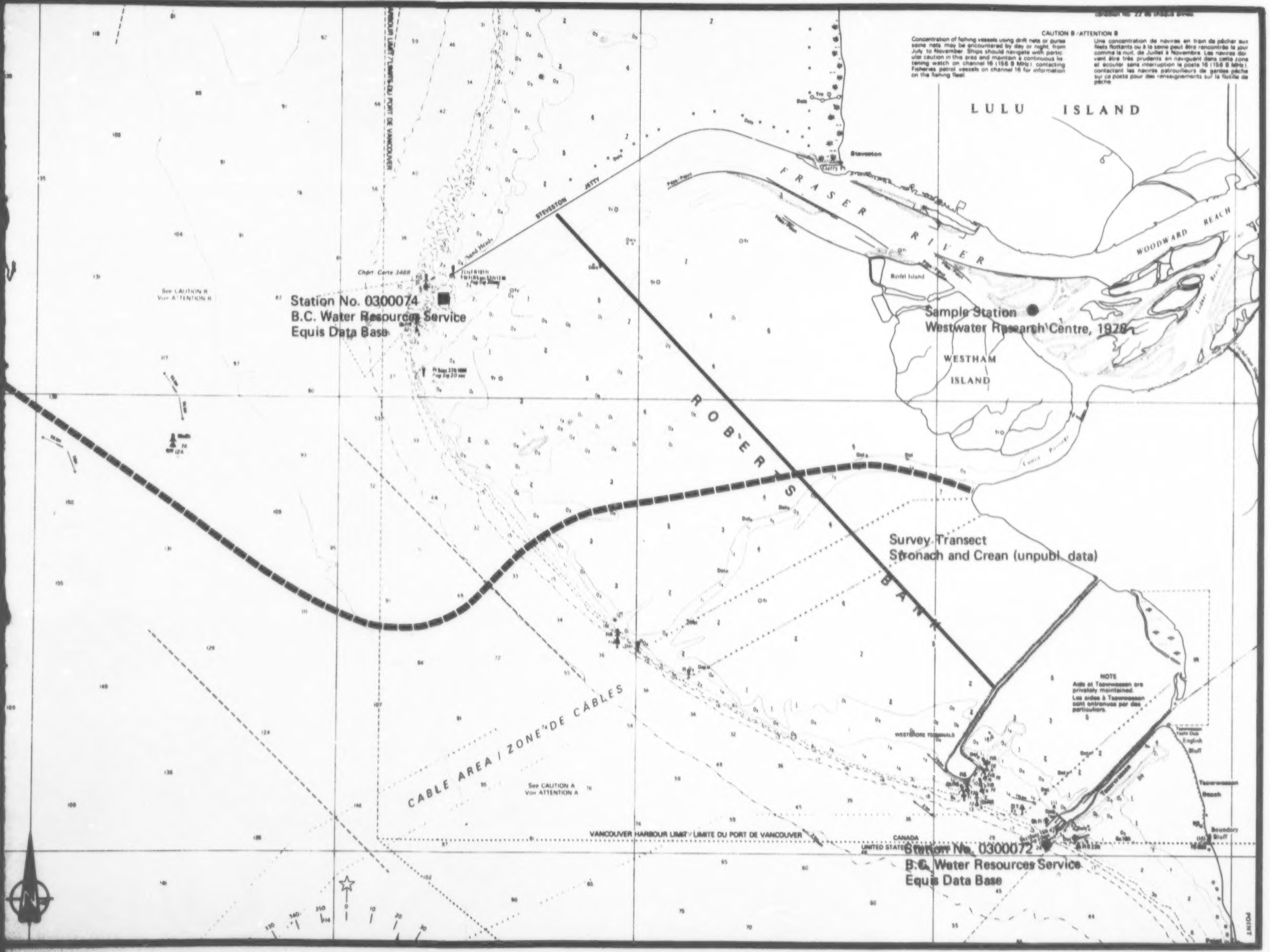

LULU ISLAND
Steveston
STEVESTON JETTY
FRASER RIVER
WOODWARD REACH
Reifel Island
WESTHAM ISLAND
ROBERTS BANK
Station No. 0300074
B.C. Water Resources Service
Equis Data Base
Sample Station
Westwater Research Centre, 1978
Survey Transect
Stronach and Crean (unpubl. data)
CABLE AREA / ZONE DE CABLES
See CAUTION A
Voir ATTENTION A
See CAUTION B
Voir ATTENTION B
VANCOUVER HARBOUR LIMIT / LIMITE DU PORT DE VANCOUVER
CANADA
UNITED STATES
Station No. 0300072
B.C. Water Resources Service
Equis Data Base
WESTSHORE TERMINALS
Tsawwassen Beach
English Bluff
Boundary Bluff
NOTE
CAUTION B / ATTENTION B

Figure 2.3-1

Water quality monitoring sites from which data were compiled and analyzed for this study.

■ ● ◆ Sample Sites

Survey Transect

Proposed Pipeline Route

0 1 2 3 4km
0 1 2 Miles
Scale 1:75,000

2.3.1 Hydrological Conditions

Fraser River discharge and Strait of Georgia tides are the two fundamental sources of water influencing Roberts Bank. The pattern of movements of this fresh and saline water mass over the tidal flats is a complex function of tide, river discharge, wind, and topography. The mixing of saline Strait of Georgia and fresh Fraser River water results in a range of brackish conditions influencing the banks.

River flow influences the tidal flats via the South Arm, which carries most (80-85%) of the Fraser's discharge, and Canoe Passage which represents approximately 5-10% of Fraser flow (Hoos and Packman, 1974). Up to 33% of Fraser flow can also pass through Albion Dyke during periods of high water level (Envirocon, 1980). Since Fraser River discharge is controlled by the snowpack, water content in the drainage basin and its rate and timing of melting, the timing, duration, and magnitude of freshet can vary considerably. However, during the freshet period (May through mid-July) flow averages more than 4,000 m^3s^{-1} and from late fall through early spring it is generally less than 1,500 m^3s^{-1} (Drinnan and Clark, 1980).

Tidal circulation patterns were measured by WCHL for B. C. Hydro and are reported in detail elsewhere (WCHL, 1980).

Basic conclusions of the work by WCHL are as follows:

1. Flows during early flood are easterly, moving to the east southeast towards Canoe Pass. Strong flow velocities of up to 1.1 m sec^{-1} are noted for the outer bank area. Surface and bottom temperatures and salinities showed similar east southeasterly movements of water towards Canoe Pass. Onshore movement of colder, more saline Strait of Georgia water was observed in the area south of Sand Heads.

2. As the flood tide progresses, southeasterly flows develop into a large clockwise gyre between the South Arm and the superport. The gyre does not appear to persist for an appreciable percentage of an average tidal cycle, possibly due to its large ratio of areal extent to average water depth.

Mass transfer is never complete around the gyre and the ebb tide sequence begins before the influence of Strait of Georgia water is felt much beyond Brunswick Point.

3. The Roberts Bank gyre appears to break down rapidly on an ebb tide. Surface and bottom flow velocities are largely controlled by surface slope during an ebb tide. Temperature and salinity isopleths maintain the shape and distribution generated during the flood tide, but are moved in an offshore direction by the ebb tide.

Further insights into patterns of water movement across Roberts Bank are shown by unpublished salinity data provided with kind permission by Drs. Stronach and Crean and shown in Figures 2.3-2 and 2.3-3.

Based on the detailed salinity profiles of Stronach and Crean, it appears that even during freshet conditions, brackish water has an appreciable influence over Roberts Bank (Figures 2.3-2, 2.3-3).

Another curious phenomenon, shown in Figure 2.3-4, is the development of a distinct front caused by the slight upwelling of saline water over the tidal flats and the resulting impoundment of less saline water supplied by the river. Seasonal aspects of this front and the circulation of impounded water are not yet fully understood.

Water flowing across Roberts Bank seems to be surprisingly well stratified at all seasons of the year (Figure 2.3-2, 2.3-3). The most pronounced departure from stratified conditions occurs during wind driven mixing (shown by October data, Figure 2.3-3) which appears to be effective to at least 5 m below water surface. Meterological data are fully reported by Monenco (1981).

The South Arm of the Fraser and the area between the coal port causeway and Brunswick Point are regions of predominant saltwater intrusions. In contrast to this, Canoe Pass appears to be much more under the influence of fresh water discharge and saline water does not seem to penetrate as strongly as in the previously mentioned areas.

Figure 2.3-2

Spring and summer salinity profiles (ppt) measured across Roberts Bank by Stronach and Crean (unpubl. data). Figure 2.3-1 shows location of survey transect.

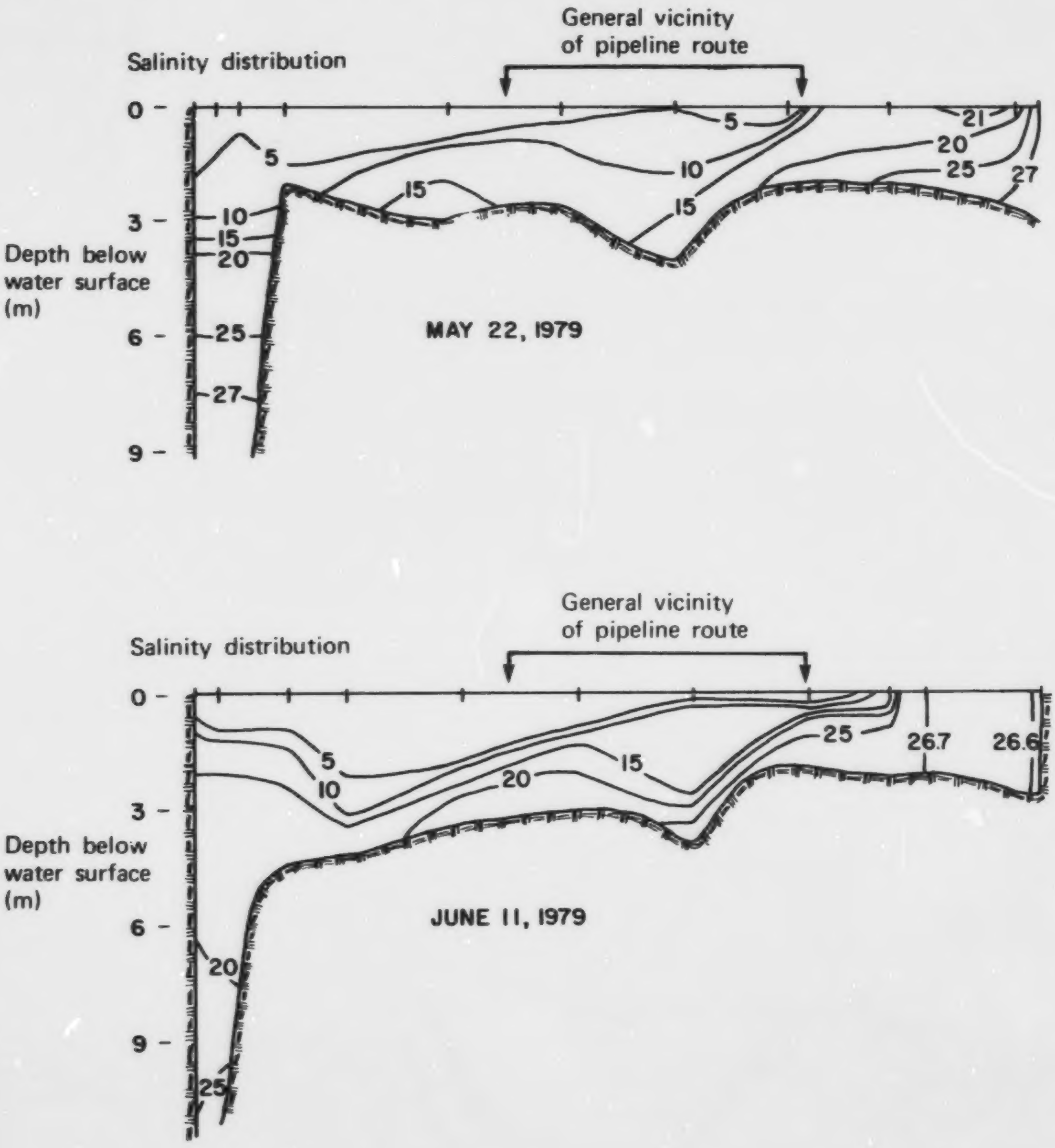


Figure 2.3-3

Fall and winter salinity profiles (ppt) measured across Roberts Bank by Stronach and Crean (unpubl. data). Figure 2.3-1 shows location of survey transect

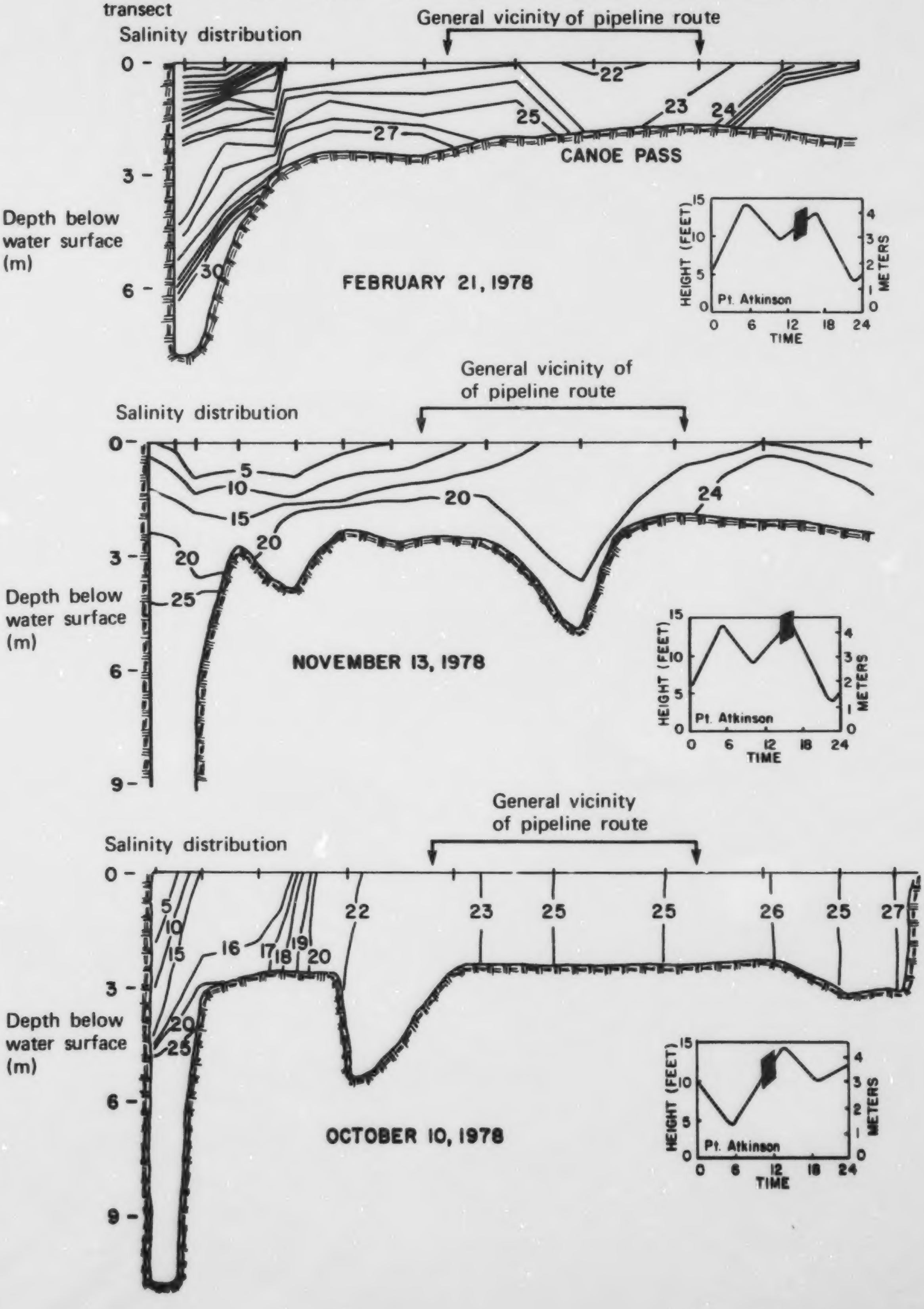
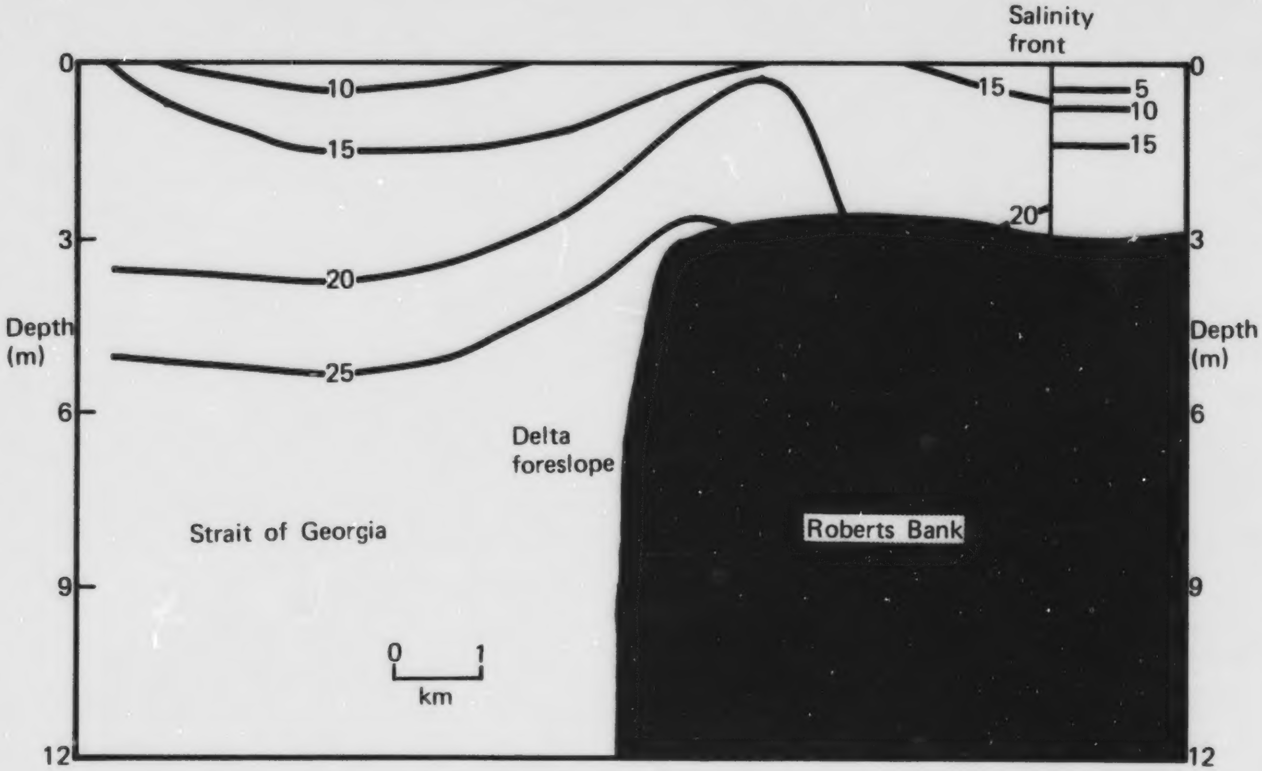


Figure 2.3-4

Salinity isopleths (ppt) along a transect (ca. 1.5km north of proposed pipeline route) taken during freshet conditions June 25, 1979 (Stronach and Crean, unpubl. data).


Salinity front
0
3
6
9
12
Depth (m)
10
15
20
25
15
5
10
15
20
Delta foreslope
Strait of Georgia
Roberts Bank
0
1
km
0
3
6
9
12
Depth (m)

Generally, as far as the pipeline route is concerned, the degree of influence of Strait of Georgia water would increase seaward towards the foreslope and in particular beyond the major influences of Canoe Pass discharge. However, extreme high tides would further augment the influence of Strait of Georgia water. The actual patterns of water movement and mixing can therefore be quite variable for relatively small temporal and spatial units.

A comprehensive temporal and spatial sampling network would be required to adequately characterize the hydrologic and therefore water quality conditions of Roberts Bank.

2.3.2 Salinity

Direct measurements close t[illegible]e pipeline route appear to be available for temperature and salinity only. Stronach and Crean provide the most comprehensive salinity data measured over the central portion of the banks along a northwest cruise track (Figure 2.3-1).

Salinities in the vicinity of Canoe Pass ranged from 15 to 26% for bottom and 5 to 25% for surface waters. Values were lowest during freshet in June and highest during the Fraser's base flow period in February (Figure 2.3-2, 2.3-3). Turbulent mixing, induced by wind, as shown in Figure 2.3-3 also occurs. Average wind speeds of 32.5 km h^{-1} with maximum hourly speeds of 50 km h^{-1} were reported for Sand Heads on this date (Atmospheric Environment Service, data records). These winds are of sufficient magnitude to warrant small craft warnings.

Another factor increasing vertical mixing velocities at the interface between salt and fresh water is strong tidal currents especially during spring tides. It would appear, then, that uniform isohaline conditions may be a commonly occurring periodic event over the banks.

Areas closer to Canoe Pass and Albion Dyke would be largely influenced by freshwater immediately discharged into this region by the Fraser River and periodically entrained during high tide.

In order to characterize water quality conditions along the pipeline route across Roberts Bank, data describing three conditions of estuarine mixed water were selected to compare the range of values and seasonal aspects of dominant effects from river water or Strait of Georgia water.

2.3.4 River Dominated Conditions

Change in river discharge is the major factor influencing seasonal water quality conditions of the freshwater mass influencing Roberts Bank. Anthropogenic factors have a pronounced influence in specific river reaches near point sources such as sewage outfalls, industrial effluent, and storm sewers. However, by the time point source pollutants are transported over Roberts Bank, they will have been mixed and diluted well below detectable limits.

Water quality data from Woodward Island (Table 2.3-1) are shown to depict seasonal characteristics of the water mass likely to influence most of Canoe Pass, inshore areas of the banks, and surface layers over the banks. Data were selected at sampling times of high flood tide when processes in the marsh would have little effect upon river water quality.

The marsh studied occurs at approximately mean sea level. Slightly brackish conditions (S, 2 to 8 ppt) occur during winter months (December through March) but during the remainder of the year, water is fresh and of river origin.

Water temperature varied seasonally with a minimum value of 2.6°C recorded in January and a maximum of 20°C in July. The effect of river flow on concentrations of dissolved ions, nutrients, and particulate matter is also apparent.

Dissolved ion concentrations (e.g. Mg, Ca) were highest during the winter-early spring period (December to March) when river flow is low and the effect of groundwater is most pronounced. During freshet (May to August) dissolved ion concentrations were reduced due to the dilution effect of snow melt. Saltwater intrusion and subsequent mixing has also influenced the concentrations of dissolved ions judging from the higher Cl^-, Ca^{++}, and Mg^{++} values in wintertime (Table 2.3-1).

Table 2.3-1 Surface water quality at Woodward Island. Mean monthly values 1977 to 1978 near high tide condition (compiled from Hall et al. in prep).

RIVER DOMINATED CONDITIONS

WATER QUALITY[1] PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Specific Conductivity µmhos/cm	2800	7800	3500	300	100	80	89	360	650	490	1500	5500
Approx. Salinity ppt	3	7	3	0	0	0	0	0	0	0	1	4
Temperature °C	2.6	5.0	7.3	9.8	13.0	16.0	20.0	19.0	13.9	9.8	3.0	4.0
Dissolved O_2	12.0	11.2	12.0	11.8	10.2	9.8	9.0	10.5	9.5	10.2	12.0	12.0
pH	7.8	7.8	7.2	8.1	7.7	8.0	7.9	7.9	8.5	7.9	-	7.8
Suspended Solids	5	13	28	55	122	61	43	29	-	12	13	8
(NO_2+NO_3)-N	.20	.18	.17	.11	.10	.06	.05	.04	-	-	.10	.24
Organic-N	.24	.13	.30	.20	.34	.13	.13	.04	-	-	.10	.12
Ortho-P	.014	.023	.017	.010	.014	.006	.003	.003	.004	.007	.008	.006
Total-P	.029	.044	.048	.070	.134	.052	.038	.024	.022	.023	.026	.024
Dissolved Cl	1430	4380	3530	150	9.2	3.7	2.4	100	-	-	675	-
Dissolved Ca	42.3	45.3	43.9	18.3	13.2	13.1	13.2	15.4	17.7	17.3	26.6	-
Dissolved Mg	104	285	113	13.7	3.6	2.2	1.9	8.6	-	-	46.8	-
Total Alkalinity	52.9	65.6	49.4	55.2	46.8	41.4	40.6	42.8	-	-	47.4	-
AcEx.-Cu (2)	-	.001	.003	.005	.008	-	-	-	-	-	-	-
AcEx.-Fe (2)	-	.25	.50	1.60	1.77	-	-	-	-	-	-	-
AcEx.-Zn (2)	-	.001	.005	.006	.012	-	-	-	-	-	-	-
Discharge (3) m^3/sec.	1144	1008	1234	2353	4559	6343	5493	3907	3369	2534	2016	1245

(1) All units expressed in mg 1^{-1} unless otherwise indicated.
(2) Mean monthly values Fraser River @ Garry Point (Hall et al., 1974); AcEx.=acid extractable phase.
(3) Mean monthly values in 1978, Fraser River @ Mission (Water Resources Branch, Environment Canada).

Nutrient levels showed seasonal variations mainly for nitrate and organic nitrogen which reached higher values during the winter low flow periods possibly due to increased groundwater influence, and brackish water intrusion. Total phosphorous increased with the large flows in April to June and was directly related to increases in suspended particulate matter. The particulate fractions of phosphorus are thought to be in relatively biologically unavailable mineral form such as ferric phosphate (Hall et al., 1974).

Seasonally, trace metal concentrations reported for copper, zinc, and iron (Drinnan and Clark, 1980; Hall et al., 1974) increase with river flow reaching maximum levels during freshet. Again, the pattern parallels that of suspended solids indicating that most metals are likely associated with particulates.

Clearly one of the more important and pronounced water quality aspects of the freshwater mass pertains to its suspended solids content. Suspended solids concentrations measured at Woodward Island peaked in May at 122 mg l^{-1} and were generally below 50 mg l^{-1} throughout most of the winter low flow period. Values are closely coupled to discharge, with peak sediment levels in surface waters often preceding maximum flow by roughly one month as was the case in Woodward Island (Figure 2.3-5).

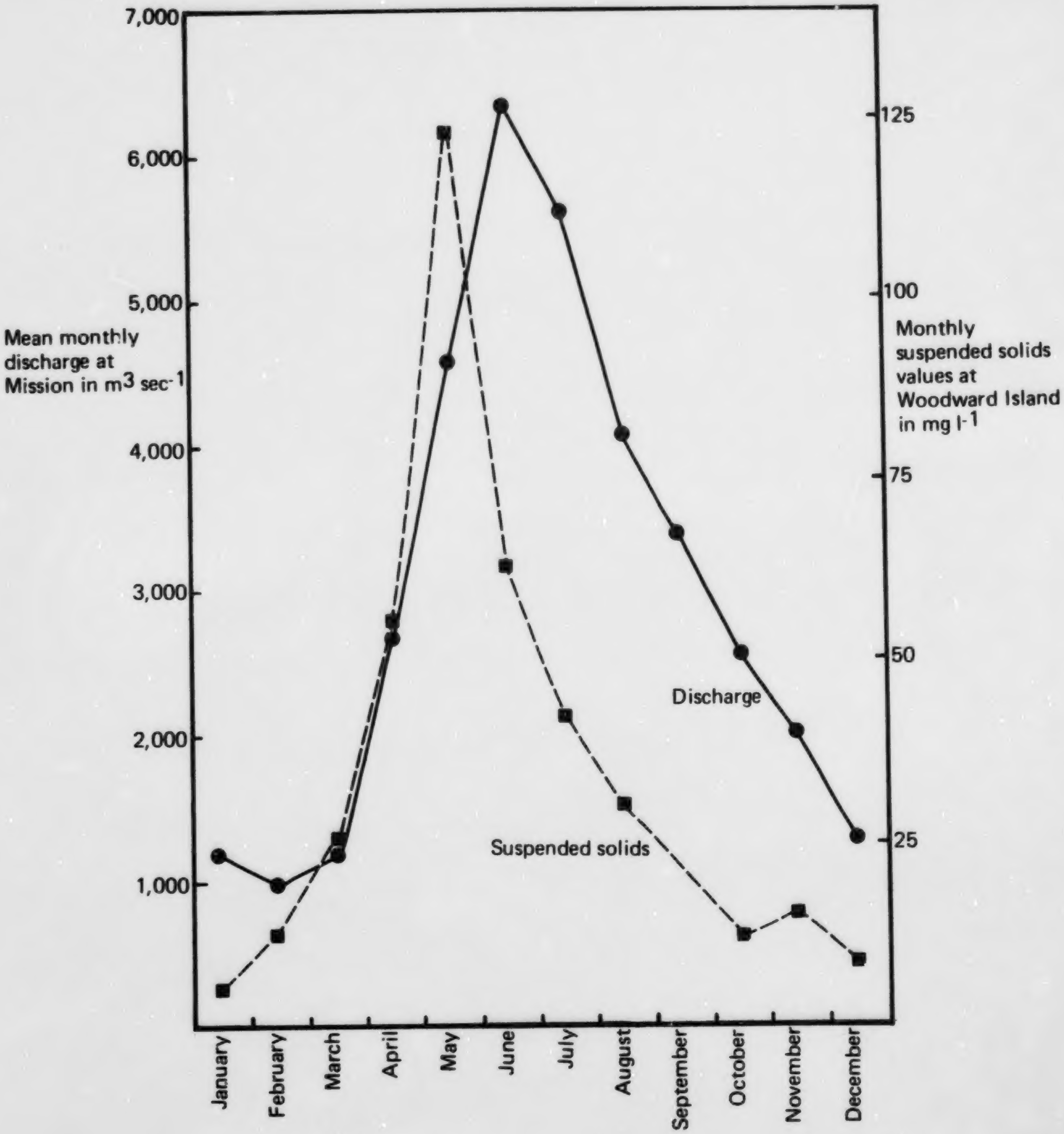
Two types of suspensions occur in this water mass, a periodic one suspended only during higher flows (bed material load) and a continuous one in which material remains in suspension at all times (wash load). The former material comprised of very coarse silt and sand makes up an average of 41% of the total suspended load transported past Port Mann; the latter material consists of silt and clay finer than 16 µm (Milliman, 1980).

The same author describes two distinct sediment transport regimes.

1. During the low flow period sediment load is dominated by silt and clay size materials. Thus, during the 9 to 10 month period from mid-summer through early spring, suspended matter concentrations within the estuary are generally less than 50 mg l^{-1}.

Figure 2.3–5

Relationships between suspended solids (Westwater Research Centre, unpubl. data) and Fraser River discharge (Water Resources Branch, Environment Canada) for 1978.



2. During freshet in spring and early summer, 80% of the annual suspended sediment load is transported into the estuary and about half of this load is comprised of sand. Suspended sediment concentrations will range from around 100 to over 1,000 mg 1^{-1} depending on geographic location, vertical depth, and tidal condition.

2.3.5 Marine Dominated Conditions

Seasonal aspects of the water chemistry in the Strait of Georgia are controlled by physical oceanographic as well as biological processes. Upwelling, estuarine entrainment, and vertical mixing are important mechanisms replenishing surface waters with nutrient salts over each winter season. During the summer period, phytoplankton growth will eventually diminish dissolved nutrient levels to very low concentrations. These processes are described by Parsons et al. (1969) for the southern Strait of Georgia in the vicinity of the Fraser estuary.

The strong dominance of oceanographic factors can be seen in the data taken at Tsawwassen terminal (Table 2.3-2) where nitrate and phosphate levels peaked in winter and levels were generally low during summer. Dissolved ions (e.g. Ca, Mg) are much higher at Tsawwassen than in Fraser River water and seasonal fluctuations in concentration are much less pronounced.

Seasonal changes in temperature and levels of total suspended solids are also far less dramatic than in the river water data of Table 2.3-1. Near surface water temperatures at Tsawwassen terminal reach minima of 5.5°C in January and 15°C in June to August. Relatively higher levels of suspended solids (10 to 20 mg 1^{-1}) are probably caused by a combination of the input of some Fraser River plume water and the summer's marine plankton production.

Total alkalinity values are generally twice that measured in the Fraser River reflecting the greater buffering capacity of water in the Strait of Georgia. Spring and summer trace metal concentrations of Cu, Fe, and Zn are much lower than in the river water which has particularly high comparative values of Fe and Zn.

Table 2.3-2 Near surface water quality 0.40 km off Tsawwassen Ferry Terminal. Data averaged for 1972 to 1979 from Station No. 0300072, EQUIS Data Base, B. C. Water Resources Service.

MARINE DOMINATED CONDITIONS

WATER QUALITY(1) PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Specific Conductivity µmhos/cm	43600	40600	41200	40200	41500	32400	26600	29700	37000	36000	41900	45200
Approx. Salinity ppt	29	26	27	27	27	22	18	20	24	24	28	30
Temperature °C	5.5	6.0	8.2	8.0	12	15	15	15	14	11	8.0	9.0
Dissolved O_2	9.9	9.2	8.4	9.0	10.7	10.6	8.1	10.4	7.5	8.2	12.3	8.0
pH	7.7	7.9	7.9	7.3	7.9	8.6	8.2	8.3	7.9	8.1	8.2	7.5
Suspended Solids	4.2	4.0	4.0	16	5.0	20	12	16	5.0	4.0	6.0	2.0
NO_3	.36	.34	.37	.25	.15	.02	.04	.03	.18	.11	-	.37
Organic-N	.08	.03	<.01	<.01	.20	.07	.11	.08	-	<.01	.09	.02
Ortho-P	-	.063	.059	.047	.045	.004	.004	.035	.040	.030	.071	.070
Total-P	.071	.074	.065	.066	.057	.026	.026	.046	.053	.046	.088	.078
Dissolved Cl	-	14500	-	-	-	12100	-	10875	-	-	-	-
Dissolved Ca	-	316	-	-	141	252	-	270	-	339	-	-
Dissolved Mg	1050	1020	955	1100	990	700	685	904	900	995	-	1140
Total Alkalinity	100	102	96.5	96.2	75.6	92.5	51.5	80.0	94.5	94.7	102	103
Total-Cu	<.001	<.001	<.001	.001	.004	.002	.003	<.001	<.001	<.001	-	<.001
Total-Fe	.023	.040	.027	.500	.069	.125	.700	.069	.164	.034	.061	.045
Total-Zn	<.005	<.005	.006	.005	.006	.020	.008	.017	<.005	<.005	-	.026

(1) All units expressed in mg l^{-1} unless otherwise indicated.

The water mass characterized by data shown in Table 2.3-2 would tend to influence most of the outer and parts of the central portion of sand flats along the pipeline route especially under conditions conducive to vertical turbulent mixing such as windy days or periods of high tidal inequalities.

2.3.6 Mixed Estuarine Conditions

Data from Sand Heads were chosen to show values reflecting conditions of strong turbulent mixing and wide fluctuations in water quality. Here conditions tend to change dramatically, both temporally (seasonal, tidal) and spatially (along a vertical gradient), fluctuating between situations dominated by the Fraser River and the Strait of Georgia. Similar conditions are likely to occur along most of the central sand flat portion of the pipeline route.

Table 2.3-3 summarizes conditions measured at Sand Heads where salinities range from near freshwater during freshet in June to highly brackish from October through to April. Temperature, suspended solids and dissolved ions tend to follow seasonal changes as a function of river discharge and values are between those encountered in more river dominated and Strait of Georgia influenced water (see Tables 2.3-1 and 2.3-2 for comparison). Nutrients, total alkalinity, and trace metals also fall between values reported for the previous two locations.

Although it would appear from Table 2.3-3 that mixed estuarine conditions are merely a mixed solution of Fraser River and the Strait of Georgia water, this is not quite the case since we know that parameters such as dissolved iron and suspended sediments have distinct non-conservative properties.

In addition to the riverine and oceanographic mechanisms influencing water quality characteristics described previously, the mixed water mass at Sand Heads is also affected by several geochemical processes typical of estuarine locations.

Adsorption/desorption mechanisms are an important aspect of estuarine water quality with respect to the natural flux of trace metals. Under brackish conditions considerable adsorption or scavenging of trace metals (e.g. Zn, Pb, Cu) by hydrous oxides of Fe and Mn can occur according to evidence supplied by Grieve and Fletcher (1976, 1977) for the Fraser estuary. As intermediate salinities

Table 2.3-3 Near surface water quality south of Sand Heads weather station. Data averaged for 1972 to 1979 from Station No. 0300074, EQUIS Data Base, B. C. Water Resources Service.

MIXED ESTUARINE CONDITIONS

WATER QUALITY[(1)] PARAMETER	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Specific Conductivity µmhos/cm	18850	35700	4330	15600	10600	1800	5670	3080	14000	26000	-	40100
Approx. Salinity ppt	12	24	29	10	7	1	4	2	9	17	-	26
Temperature °C	3.5	6.0	7.0	8.0	12.5	14	15	15	18	12	6	7.9
Dissolved O_2	11.9	9.2	9.1	9.5	10.8	8.0	8.0	8.8	7.7	10.2	11.6	8.5
pH	8.3	8.0	7.9	8.0	7.5	7.9	8.5	8.8	8.0	8.1	7.9	7.4
Suspended Solids	4.4	7.0	3.0	-	90	89	38	23	11	4.2	3.0	3.0
NO_3^-	.22	.32	.34	-	.13	.16	.06	.05	.07	.13	.20	.31
Organic-N	.08	<.01	.01	.05	.23	.18	.10	.09	.10	<.01	.11	<.01
Ortho-P	.03	.05	.06	.02	<.01	<.01	.02	.01	.01	.03	.03	.06
Total-P	.04	.06	.07	.04	.10	.30	.08	.05	.03	.05	.06	.07
Dissolved Cl	-	-	-	-	-	-	-	-	-	-	-	-
Dissolved Ca	178	231	-	-	-	22.6	-	29.6	-	311	162	295
Dissolved Mg	520	735	565	355	300	53	81	455	550	985	855	845
Total Alkalinity	64	87.5	99.7	68.5	53.5	46	45.5	43.5	35	88.8	74.1	95
Total-Cu	<.001	<.003	.002	.002	.004	.004	.003	<.001	.001	<.001	.002	.001
Total-Fe	.107	.114	.400	.300	-	1.20	1.40	1.20	.240	.074	.320	-
Total-Zn	<.005	.009	.007	-	<.005	.020	.012	.027	<.005	<.005	.005	.018

(1) All units expressed in mg l^{-1} unless otherwise indicated.

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are reached, iron associated with suspended sediments dissolves, and trace metals such as Co, Cu, Mn, and Pb move into the dissolved phase and are likely associated with dissolved iron colloids. The biological availability of these elements changes with the changing dissolved iron concentrations (Fletcher et al., 1981).

In conjunction with the above processes geochemical mechanisms tend to influence sedimentation by increasing the flocculation of suspended sediment particles. Much of the fine suspended matter transported by the Fraser River into the estuary is effectively removed through flocculation and settling as more saline conditions are encountered.

A more complete description of the complex chemical behaviour of elements in mixed estuarine conditions is beyond the scope of this report. In any case, only a limited amount of water quality data is available which show the detailed chemical aspects and types of exchangeable phases required to understand geochemical processes, especially for sediment-water relations.

Mixing of the fresh and saline waters also has an influence on the bacterioplankton in the estuary which could have some influence in the estuarine decomposition processes and the detritus based food web. Fresh water bacterioplankton appear to become inactive when they enter the saline water of the Strait of Georgia. In this dead or inactive state, the Fraser River bacterioplankton probably contribute to the particulate and dissolved organic matter pools. However, marine bacterioplankton from the Strait of Georgia appear to remain active when they move into the brackish and freshwater environment of the Fraser River plume (Pastor, 1980).

2.4 Marsh Habitat (Brunswick Point)

2.4.1 Background Information

2.4.1.1 Plant Distribution

Of the roughly 2,362 ha of brackish marsh habitat on the Fraser estuary foreshore, Brunswick marsh represents approximately 7% or 164 ha. This area of wetland also represents the estuary's main vegetational transition zone between marsh plant species representative of freshwater to brackish habitats to the north and those characteristic of more saline environments southeast and in Boundary Bay. Brackish marsh vegetation at Brunswick Point is typically dominated by bulrushes such as *Scirpus americanus*, *S. validus*, the sedge *Carex lyngbyei*, and the cattail *Typha latifolia*. Saltmarsh vegetation occurs only at the southeast end of the marsh and is represented by dominant species such as the bullrush *S. maritimus*, saltgrass *Distichlis spicata*, and saltwort *Salicornia viginica*. The distribution of dominant marsh plant species has been mapped for the entire Brunswick marsh area (Beak, 1977). The floristic aspect of marsh communities close to the proposed pipeline route was part of the botanical research undertaken by Glen L. Porter for his M.Sc. thesis work at UBC. The thesis is currently in preparation and the following excerpt is from a memo describing research activities in the summer of 1978.

> "One transect runs 1,420 m across the point (Brunswick) from north to south. On the river side, bare mud is being colonized mainly by *Scirpus americanus* and also by *Eleocharis palustris*; these are the principal species in the lower fringes of this marsh area. Higher up *Carex lyngbyei* and *Agrostis alba* are the dominant species in an extensive community which also includes *Triglochin maritimum*, *Sagittaria latifolia*, *Bidens cernua*, *Lilaeopsis occidentalis*, *Potentilla pacifica* and several other species. *Ruppia maritima* is common in channels."

2.4.1.2 Plant-Environment Relationships

Vegetated habitats south of the proposed pipeline crossing were the subject of investigation by Moody (1978) whose objective was to describe the vegetation, assess its primary production, decomposition and succession, and relate these to various environmental factors. Her study provides values for the limits of vegetation growth which are governed by the dyke in the upper level and the degree of tidal exposure and submergence in lower levels. Little plant growth occurred below 2.82 m (above chart datum at Tsawwassen). At this elevation the mean diurnal exposure period is approximately 9.1 hours, all of which occurs in daylight hours during May and June. As the cycle of tidal exposure and submergence changes from summer to winter pattern, almost all of the mean diurnal exposure period occurs during hours of darkness throughout December and January.

It is essential to stress at this point that tidal elevation is one of the most important environmental factors governing the growth and distribution of marsh plants. The degree of drainage and standing water regulates physico-chemical processes in the soil which are critical for plant growth. Linthurst and Seneca (1980) demonstrated experimentally that soil surface elevation changes of as little as 40 cm represented a 48% change in the soil complex.* This change was concluded to be significant enough to influence plant growth. Because of the large tidal range and turbid waters in the Fraser estuary, daylight exposure also becomes critical, especially during periods of active growth and photosynthesis in early summer.

2.4.1.3 Primary Production and Life History Characteristics

The sedge (Carex lyngbyei) and bulrushes (Scirpus spp.) occurring in Brunswick marsh are the most productive plants dominating the area. Average peak aboveground standing crop for C. lyngbyei (measured by Moody, 1978) was 909 g m^{-2} dry weight in July. Bulrushes begin growth several weeks later than the sedge and their peak standing crops averaged at 565 g m^{-2} (S. maritimus) and 397 g m^{-2} (S. americanus) in August (Moody, 1978).

Insights into seasonal and life history aspects of Lyngbyei's sedge and bulrush species are available from research conducted by Kistritz and Yesaki (1979) and Hall and Yesaki (in prep.).

Because of the dominance of C. lyngbyei along the pipeline route several conclusions from this work are noteworthy:

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* Numerous substrate physico-chemical characteristics were combined into a soil system component measurement using factor analysis.

1. Rapid shoot growth (ca. 2 cm day^{-1}) occurs during April, May and June at which time below ground carbohydrates and nutrients are being translocated upwards from stored reserves in roots and rhizomes.

2. Below ground biomass always exceeds that found aboveground even during July's aboveground peak biomass which represents only 20% of the total plant biomass, the balance occurring below ground as roots and rhizomes.

3. Starting in late June, nutrients, as well as carbohydrates produced by photosynthesis, are drawn back down into below ground organs to replenish stored reserves for next seasons growth. At the same time, overwintering shoots emerge through the soil in August giving the plants a "head start" the following spring.

4. The growing phase for C. lyngbyei is essentially over in August and by November there is little evidence remaining of green shoots.

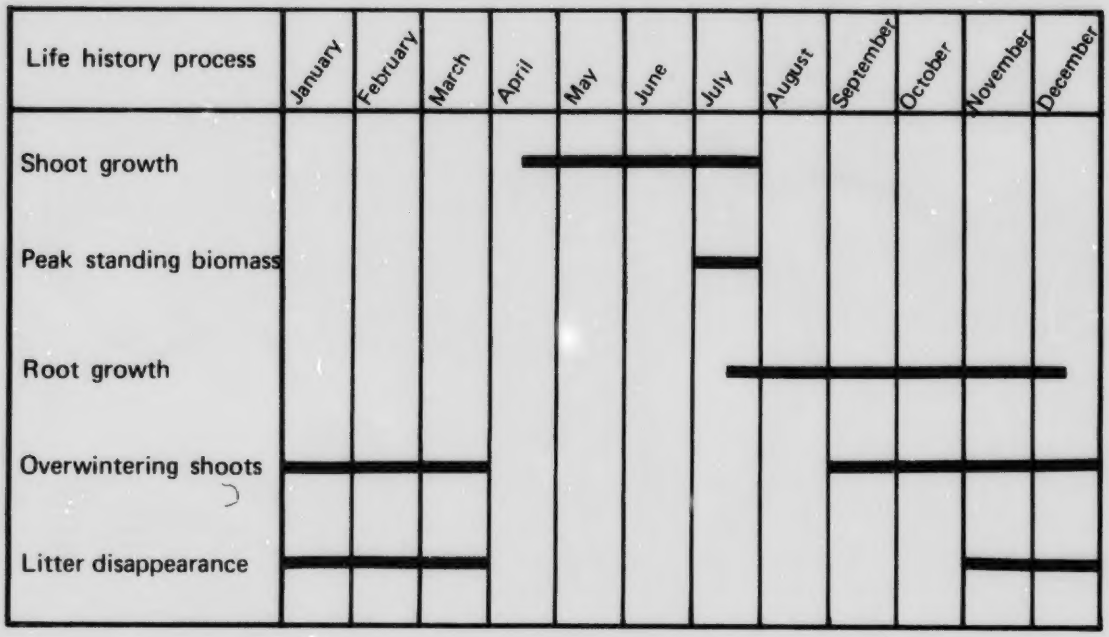
5. Of the plant biomass remaining on the marsh surface in late summer, approximately two-thirds is lost via tidal export and decomposition over the winter period and the remainder is buried by new sediment deposited during river freshet the following spring.

Temporal and quantitative aspects associated with the life history considerations described above would exhibit some degree of variability depending on year-to-year variations in weather patterns and differences in tidal elevation, drainage and wave exposure. However, the life history strategies described above are generally useful in identifying sensitive periods in the seasonal development of the marsh (Figure 2.4-1).

In general then, there are two distinct components to the marsh plant community: aboveground annual growth of vegetative and reproductive shoots and the inconspicuous but equally important perennial belowground organs. Belowground biomass in sedge and bulrush plants of up to 5.6 kg m^{-2} ash-free dry weight have been measured by Kistritz and Yesaki (1979), and Hall and Yesaki (in prep.) to a sediment depth of approximately 20 cm. Also, roughly 70 to 80% of the live below ground organs of Lyngbyei's sedge and bulrushes can be found within the

Figure 2.4–1

Seasonal distribution of important life history processes of tidal marsh vegetation.



upper 20 to 30 cm of sediment. The arrowgrass Triglochin maritima is a clear exception to this pattern of the average depth of root penetration since its live roots have been detected to depths of up to one metre (Moody, 1978).

Although belowground organs are essential to the growth and survival of the marsh plants, it is the aboveground biomass which is of direct importance to secondary levels in the marsh/estuarine ecosystem.

2.4.1.4 Energy Flow Dynamics

In comparison to marsh-wildfowl relationships, the links and interdependencies between marsh vegetation and estuarine aquatic organisms is more obscure and indirect since energy transfers between marsh primary production and secondary consumers is through a detritus based pathway. Considerable empirical evidence is available in the scientific literature showing examples of estuarine detritus based food webs and the ecological importance of tidal marsh vegetation. The ecological role of Fraser estuary marshes has been described in detail on a conceptual level in various reports (e.g. Dorcey et al., 1978; FRES, 1978; Kistritz, 1978; Valiela and Kistritz, 1980).

A fundamental argument for the preservation of existing marsh habitat in the Fraser estuary is based on the hypothesis that estuarine growth and rearing processes in juvenile salmon are driven by phytodetritus production originating in tidal marshes. A further aspect of this juvenile salmon-marsh habitat relationship is that it may ultimately control the survival of returning adult spawners thereby influencing the size of harvests available to the commercial fishery. This hypothesis has been the focus of rigorous conceptual and modelling studies (Dorcey et al, 1978; Valiela and Kistritz, 1980) as well as recent scientific field investigations (Levy et al., 1979; Levy and Northcote, 1981).

This work has essentially confirmed that estuarine growth and rearing of juvenile salmon is highly related to various aspects of the marsh habitat. However, it remains unclear what effect a juvenile marsh residency period has on adult survival. Nor is it known which Fraser River salmon stocks contribute residing juveniles to the estuary or, if so, what the proportionate contribution is.

Other important ecological attributes of tidal marsh environments in the Fraser estuary relate to processes of nutrient cycling, conservation, regulation, and availability. Lyngbyei's sedge in particular has a large capacity for nutrient storage (a conservation and regulatory function) and makes essential nutrients such as phosphorus and nitrogen available to microbial and detritovore levels via plant leachates and phytodetritus (Kistritz et al., in press).

2.4.2 Pipeline Route

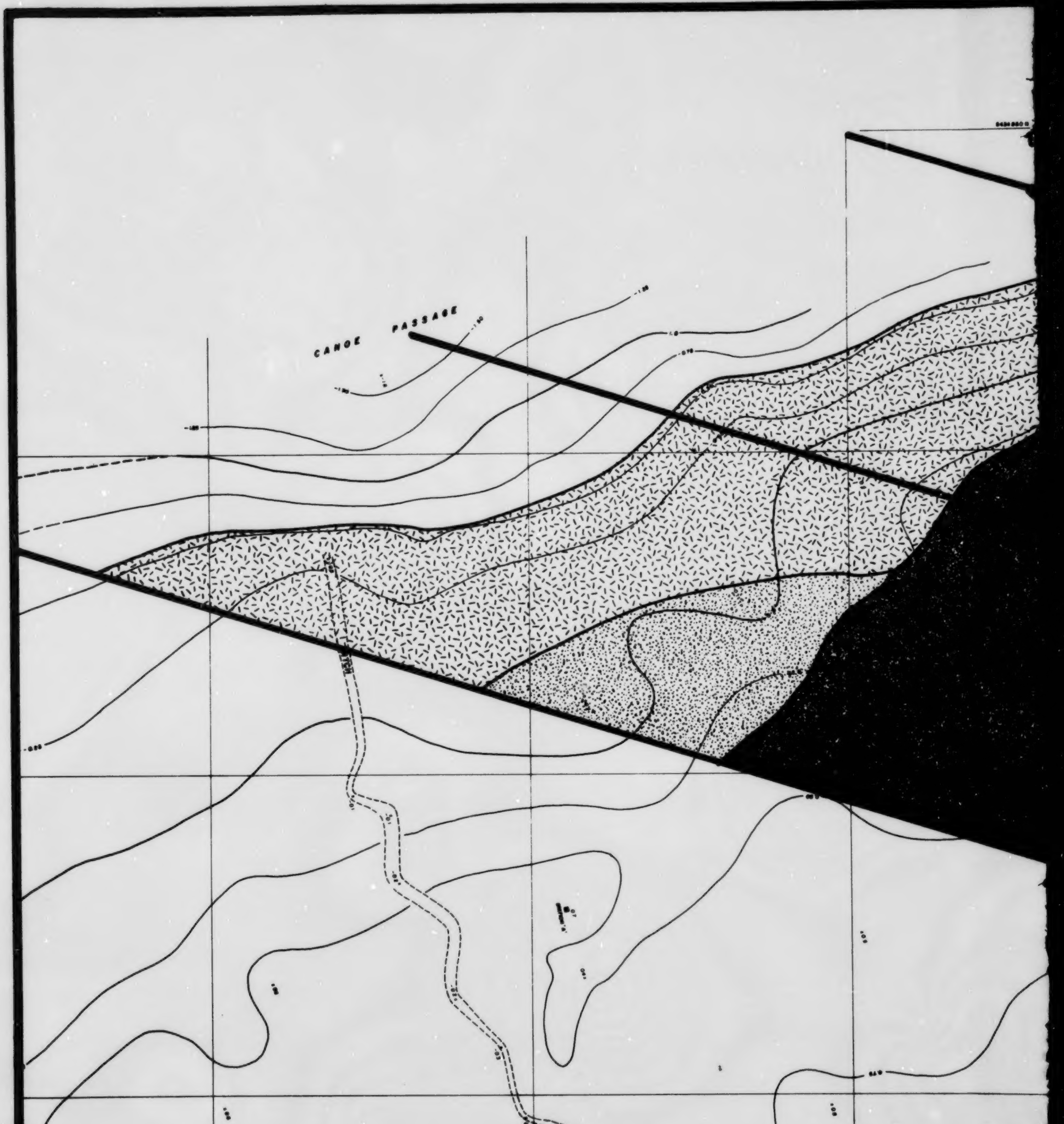
The direction of the proposed pipeline route across Brunswick marsh is approximately W17°N in the far northeast section of the marsh facing Canoe Pass.

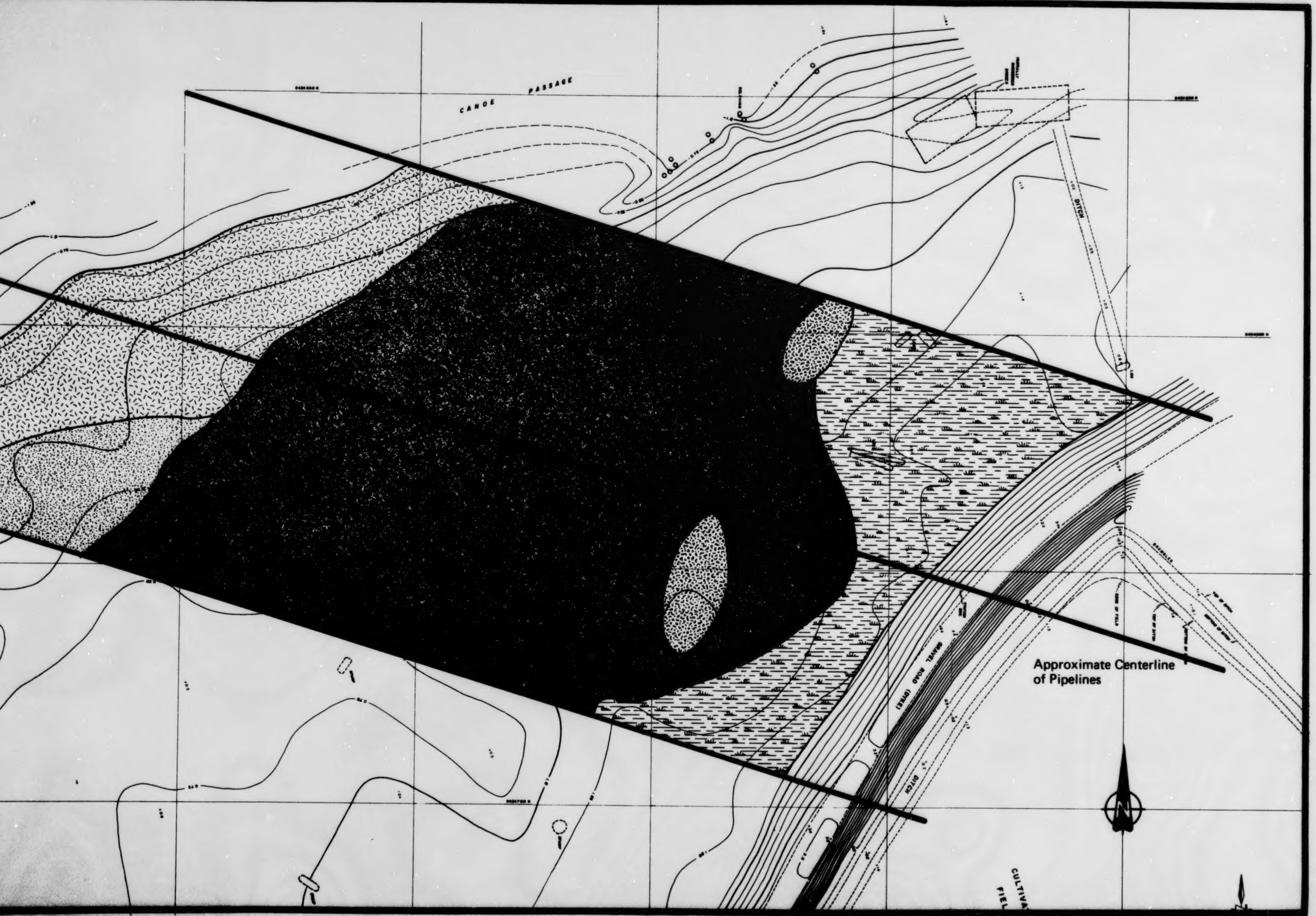
For the purpose of this study, a distance of 50 m on either side of the proposed pipeline route was chosen to delineate the maximum total area likely to be disturbed by pipeline construction activities. Once a detailed topographic map was available for this area, a field survey was undertaken in order to describe the marsh flora with respect to exact elevation contours. Results of marsh soil chemistry based on two core samples are given in Tables 2.2-3, 2.2-4, 2.2-5, 2.2-6 and discussed in Section 2.2.2.

Three transects were set up to position observed vegetation features such as species present, transitional boundaries, stem densities, and average shoot height. Figure 2.4-2 shows those field observations which were most amenable to delineation on a map. Plant species associations in the upper marsh areas were too complex to separate into further community types without additional field studies or more sophisticated sampling techniques. The main vegetation zones are mapped in Figure 2.4-2, shown in profile in Figure 2.4-3 and are discussed beginning with the lower marsh.

1. Scirpus Zone

This zone is almost entirely composed of the bulrush *Scirpus americanus* making up the outer boundary of the marsh (separating it from the bare mudflats). The outer fringe of the marsh is a distinct boundary closely following the -0.5 m Geodetic elevation contour which is 0.5 m below mean sea level. The measured stem density of *S. americanus* was from 350 to 550 m^{-2} and the average shoot height was approximately 0.75 m.


CANOE PASSAGE



CANOE PASSAGE
DITCH
Approximate Centerline of Pipelines
GRAVEL ROAD
DITCH
CULTIVA
FIEL

Figure 2.4-2

Map showing general distribution of major vegetation zones within a proposed 100m wide working area reserve of Brunswick Point shore approach.

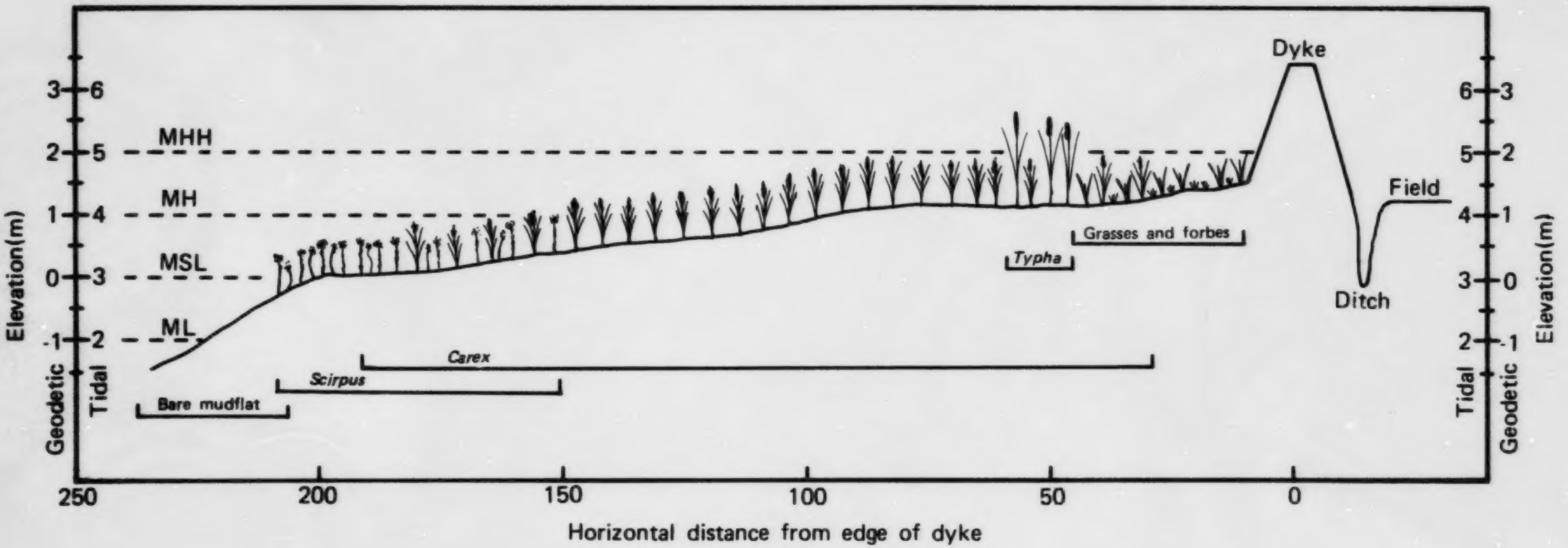
Scirpus
Scirpus – Carex
Carex
Typha
Mixed grass and forbe
Transect

Elevations are in metres referred to Geodetic Datum which is approximately 3 metres above tidal (chart) datum.

0 5 10 20 30 40m
Scale 1:750

Figure 2.4-3

Profile of dominant marsh vegetation zones along centreline of proposed pipeline route at Brunswick Point.



Tidal levels
MHH - mean high high
MH - mean high
MSL - mean sea level
ML - mean low

2. Scirpus - Carex Zone

The Scirpus zone expands towards the southwest and begins to merge with Carex lyngbyei into a distinct, separate community. Other species found in this zone were: Triglochin maritima and Juncus balticus. The upper boundary of S. americanus is within ca. 0.25 m of mean sea level.

3. Carex Zone

By far the most extensive area of marsh is occupied by Carex lyngbyei and associated species. C. lyngbyei was found growing from lower levels of 0 to 0.25 m up to 1.25 m (Geodetic). This zone was comprised of a gradient of plant associations which increased in diversity at higher elevations. Some associated species occurred in distinct patches such as the purple Loosestrife Lythrum salicaria whereas others such as Bentgrass Agrostis alba were more widely distributed throughout the zone. Several subcommunities within the Carex zone were evident, ranging from almost pure stands of the sedge to very diverse associations. Pure stands of C. lyngbyei were most abundant in lower levels of the zone and contained the most vigorous growth evident with stem densities of ca 650 m^{-2} and average shoot height of 0.8 to 1.2 m.

In rough order of decreasing abundance, plants observed in this zone were: Carex lyngbyei, Agrostis alba, Leersia oryzoides, Sium suave, Lythrum salicaria, Potentilla pacifica, Troglochin maritima, Deschampsia cespitosa, Eleocharis palustris, Sagittaria latifolia, Lilaeopsis occidentalis, Bidens cernua, Menyanthes trifoliata, Iris pseudacorus, Scirpus validus.

4. Typha Zone

Above mean high tide elevation near the upper end of the Carex zone were two distinct cattail stands. The cattails were found to be growing in several centimetres of standing water in an area of apparently poor drainage. Only a few aquatics such as Sagittaria latifolia and Iris pseudacorus were seen to be associated with the Typha latifolia stand.

5. Mixed Grass and Forbe Zone

The upper end of the marsh is comprised of a plant community typical of disturbed sites and thus dominated by several introduced weed species. This zone occupies the tidal flats from the foot of the dyke to approximately mean high tide. This region of the marsh is periodically disturbed because it is in the location of the storm strand line. The following species were observed in this zone: *Festuca arundinacea*, *Agrostis alba*, *Lathyrus* spp., *Convulvulus soldanella*, *Melilotus alba*, *Holcus lanatus*, *Trifolium* spp., *Sonchus oleraceus*, *Epilobium* spp.

The five zones described above make up a total band of vegetated tidal flat, 50 m on either side of the proposed pipeline route, of 1.765 ha representing ca. 1% of the entire Brunswick marsh area.

2.5 Benthic Communities

2.5.1 Background Information

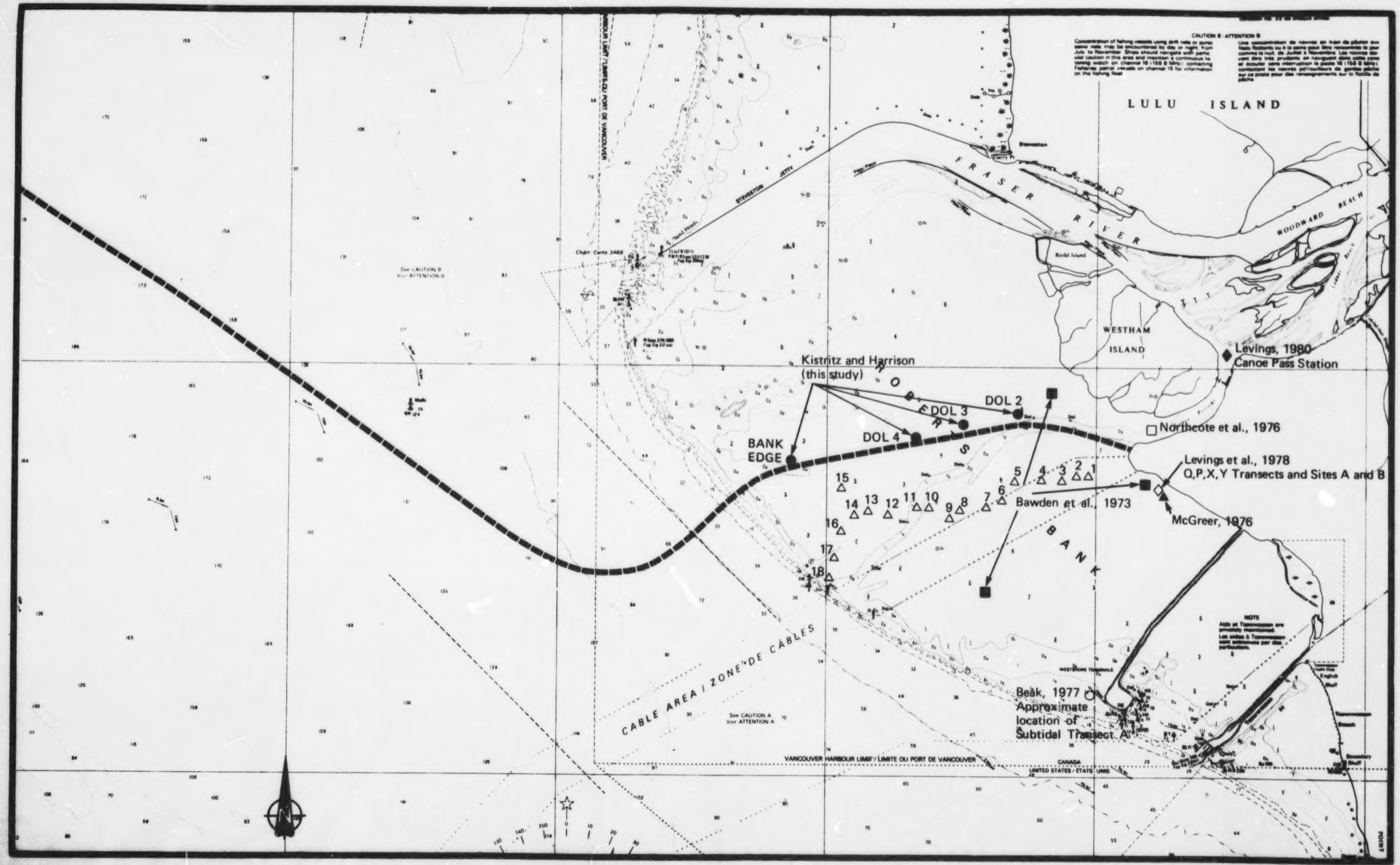
The systematic collection of quantitative ecological data on the benthic invertebrates of Roberts Bank was begun relatively recently (Bawden et al., 1973). The data which form the primary source of information for this report come from Bawden et al. (1973), Levings and Coustalin (1975), B. C. Research (1976b), Northcote et al. (1976), Levings et al. (1978) and Levings (1980). The relevant sampling locations selected from these reports are shown in Figure 2.5-1. Comparison among authors is complicated by differences in sampling methods, sorting methods, "level" of taxonomy, and timing of sampling collections; these factors are summarized in Table 2.5-1.

In most surveys, invertebrates are identified to "lowest taxon possible". Species lists, therefore, often reflect the taxonomic expertise and interests of the investigator as much as the nature of the biotic community being sampled. This is most often a difficulty with rare species, juveniles, or smaller individuals. It is not possible a posteriori to standardize the level of "taxon" reported by different authors without the loss of a considerable amount of information, therefore a "species list" of the area was compiled with taxon names as given by the original authors. In addition, the taxa were grouped into larger categories and data recalculated for the more inclusive taxonomic groupings.

Benthic invertebrates are usually grouped according to:

(a) Position on the substrate - with the epi-benthos occurring above or near the sediment-water interface and the in-benthos living below the interface.

(b) Size - macrobenthos are those metazoans retained on a mesh of 0.5 mm or larger; the meiobenthos are metazoans which pass a 0.5 to 1.0 mm mesh but are ratained on a mesh <0.1 mm and the microbenthos are the tiny unicellular organisms such as bacteria and ciliates.


CAUTION B · ATTENTION B
Concentration of fishing vessels using drift nets or purse seine nets may be encountered by day or night, from July to November. Ships should navigate with particular caution in this area and maintain a continuous listening watch on channel 16 (156.8 MHz) contacting Fisheries patrol vessels on channel 16 for information on the fishing fleet.
LULU ISLAND
FRASER RIVER
WOODWARD REACH
STEVESTON JETTY
Steveston
Reifel Island
WESTHAM ISLAND
Levings, 1980
Canoe Pass Station
Kistritz and Harrison
(this study)
ROBERTS BANK
DOL 2
DOL 3
DOL 4
BANK EDGE
Northcote et al., 1976
Levings et al., 1978
Q,P,X,Y Transects and Sites A and B
Bawden et al., 1973
McGreer, 1976
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
See CAUTION B
Voir ATTENTION B
Chart · Carte 3488
CABLE AREA / ZONE DE CABLES
See CAUTION A
Voir ATTENTION A
Beak, 1977
Approximate location of Subtidal Transect A
WESTSHORE TERMINALS
NOTE
VANCOUVER HARBOUR LIMIT / LIMITE DU PORT DE VANCOUVER
CANADA
UNITED STATES / ÉTATS-UNIS
VANCOUVER HARBOUR LIMIT / LIMITE DU PORT DE VANCOUVER
POINT

Fig

App
majo

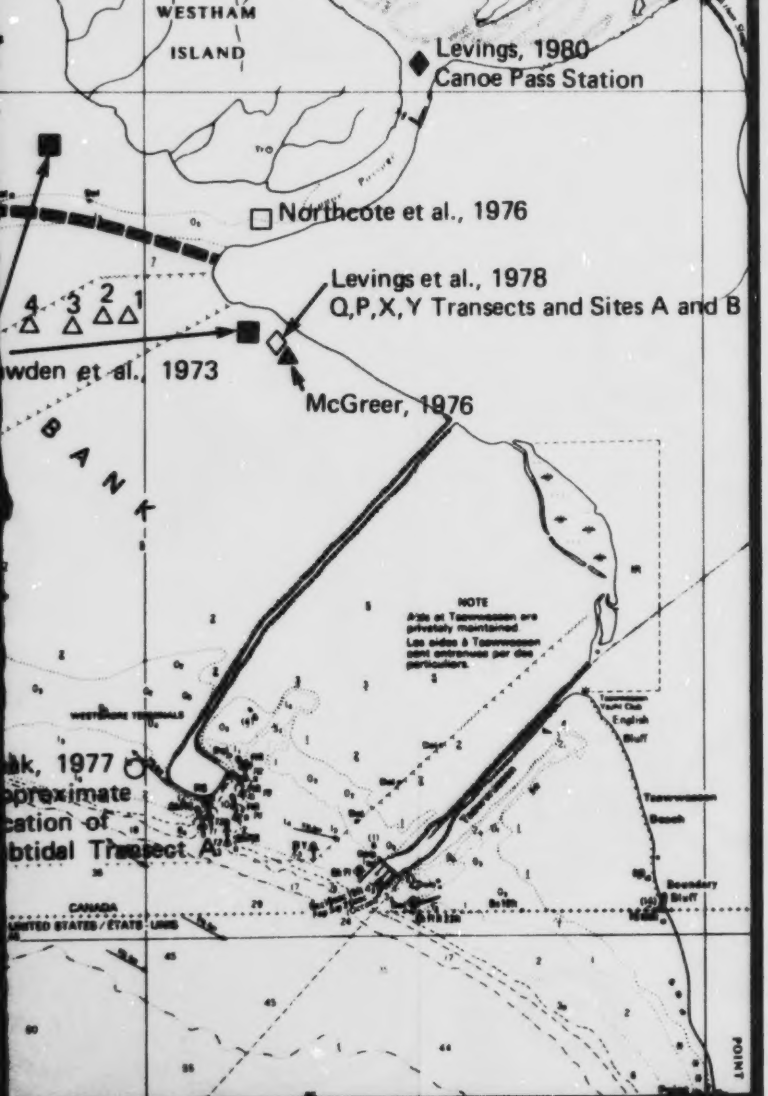

CAUTION 8 / ATTENTION 8
Concentration of fishing vessels using drift nets or purse seine nets may be encountered by day or night, from July to November. Ships should navigate with particular caution in this area and maintain a continuous listening watch on channel 16 (156.8 MHz), contacting Fisheries patrol vessels on channel 16 for information on the fishing fleet.
Une concentration de navires en train de pêcher aux filets flottants ou à la seine peut être rencontrée le jour comme la nuit, de Juillet à Novembre. Les navires doivent être très prudents en naviguant dans cette zone et écouter sans interruption le poste 16 (156.8 MHz), contactant les navires patrouilleurs de gardes-pêche sur ce poste pour des renseignements sur la flotille de pêche
LULU ISLAND
RIVER
WOODWARD REACH
Reifel Island
Ladner Reach
WESTHAM ISLAND
Levings, 1980
Canoe Pass Station
Northcote et al., 1976
Levings et al., 1978
Q,P,X,Y Transects and Sites A and B
4 3 2 1
wden et al., 1973
McGreer, 1976
BANK
NOTE
Aids at Tsawwassen are privately maintained.
Les aides à Tsawwassen sont entretenues par des particuliers.
WESTSHORE TERMINALS
ak, 1977
pproximate
cation of
btidal Transect A
Tsawwassen Yacht Club
English Bluff
Tsawwassen Beach
Boundary Bluff
CANADA
UNITED STATES / ÉTATS-UNIS
POINT

Figure 2.5-1

Approximate locations of sample sites for the major benthic studies on Roberts Bank.

●◇□▲ Study Sites

▬ Proposed Pipeline Route

△ ROB Transect

0 1 2 3 4km

0 1 2 Miles

Scale 1:75,000

Table 2.5-1 Comparison of methods used for collecting benthic invertebrates.

Author(s)	Collection Date(s)	Sampling Apparatus	Mesh (mm)	Comments
Bawden et al. (1973)	1972	Box corer (0.25m^2)	4.0	only large macrobenthos
Levings & Coustalin (1975)	10 - 11 Dec 1973	Quadrat (0.06 m^2 to 2 cm)	0.5	ROB transect
	11 Sept 1973	Quadrat (0.25 m^2)	0.5	FRAPER transect
B. C. Research, (1976 b)	8 Jan 1976	Quadrat (0.06 m^2 to 10 cm)	1.0	before cable burial
	5 Feb 1976	Quadrat (0.06 m^2 to 10 cm)	1.0	after cable burial
Northcote et al. (1976)	11 Oct, 28 Nov 1972; 20 Mar, 28 Aug 1973	Peterson Grab (0.06 m^2)	0.61	"inbenthos"
	28 Nov 1972; 20 Mar, 28 Aug 1973	Epibenthic net (4.9 m^2)	1.09	"epibenthos"
Beak (1977)	Apr - Jul	Ponar Grab (0.053 m^2)	0.5	"inbenthos"
Levings et al. (1978)	Monthly Jun 1975 - Apr 1976	Corer (0.5 m^2 to 20 cm)	0.5	Sites A & B
Levings (1980)	Monthly Feb - Sept 1978	Drift Net & Submersible Pump (at surface, 2 - 3 m depth & 0.5 m off bottom)	0.5	"epibenthos"

(c) Functional groups which reflect ecological relationships - e.g. feeding relationships - deposit feeders which feed from organic material in the sediments; filter or suspension feeders which filter or trap edible material from seawater; predators which eat other animals.

Each of these types of categorizations will be used throughout this report where appropriate. Unfortunately, very little is known about the meiobenthos of the Fraser Delta. The only comprehensive treatment of the group is given by Harrison (1981) for a site (Iona Island) on the northern part of Sturgeon Bank 17 km to the north of the proposed pipeline route. Both Bawden et al. (1973) and B. C. Research (1976b) sampled the "meiobenthos" but the mesh size used by these authors (0.25 mm) allows most of the meiofauna to pass through.

The benthic invertebrate species which occur in the vicinity of the pipeline route can also be grouped into more inclusive taxonomic groups - at the level of "class". Within any given class there is a tremendous diversity of form and function, however members of one class are generally more closely functionally related than species belonging to different classes. The species with which this report is concerned fall into the five following classes (with some of the more poorly represented species included in a sixth category = "others"):

Phylum Mollusca
    A. Class Bivalvia (e.g. clams, oysters, mussels)
Phylum Annelida ("worms")
    B. Class Polychaeta
    C. Class Oligochaeta
Phylum Arthropoda
    D. Class Crustacea
    E. Class Insecta
    F. Others

A list of taxa recorded from the study area is given in Table 2.5-2. A total of 62 taxa have been identified from benthic and epibenthic collections in the vicinity of the proposed pipeline route. Of these, eight taxa were "common" and occurred in a variety of habitats, six taxa were "common" to "abundant" but limited to the intertidal flats and two "abundant" taxa were mostly limited to Canoe Pass.

Table 2.5-2

List of taxa recorded from benthic and epibenthic samples collected in the vicinity of the proposed pipeline route.

TAXA	Beak (1977)	Bawden et al. (1973)	Levings & Coustalin (1975)	McGreer (1976)	Northcote et al. (1976) (inbenthos)	Northcote (epibenthos)	Levings et al. (1978)	Levings (1980)^2	Abundance^1
NEMERTINA	X		X	X	X	X	X		C
NEMATODA					X	X			*
ANNELIDA									
Oligochaeta			X	X	X	X	X	X	A
Polychaeta									
Amphicteis sp.			X	X	X		X		C
Heteromastus sp.							X		R
Glycinde picta	X		X				X		R
Nereis (Neanthes) limnicola			X	X	X	X	X		C
Eteone longa	X		X	X			X		(C)
Eteone sp.					X	X			(C)
Eulalia sp.							X		R
Manayunkia aestuarina			X	X			X		(A)
Pygospio elegans			X	X			X		(C)
Polydora sp.							X		R
Polydora (kempi) japonica	X			X					R
Armandia brevis	X		X						R
Paraonis platybranchia			X						R
MOLLUSCA									
GASTROPODA									
Batillaria attramentaria							X		R
PELECYPODA									
Macoma balthica (?)	X		X	X	X	X	X		C-(A)
Mytilus edulis							X		R

Table 2.5-2 Cont'd.

TAXA	Beak (1977)	Bawden et al. (1973)	Levings & Coustalin (1975)	McGreer (1976)	Northcote et al. (1976) (inbenthos)	Northcote (epibenthos)	Levings et al. (1978)	Levings (1980)^2	Abundance^1
Mya arenaria	X						X		R
Venerupis japonica							X		R
Protothaca staminea	?X						X		R
Musculus substriatus			X						R
Tellina carpenteri		X							R
ARTHROPODA									
Crustacea									
Copepoda									
Harpacticoida		X	X	X	X	X	X	X	*
Calanoida					X	X		X	R
Cyclopoida					X	X			R
Cladocera					X	X		X	R
Cumacea					X	X		X	R
Cumella vulgaris	X			X			X	X	R
Tanaidacea									
Tanais stanfordi							X		(C)
Tanais sp.			X	X					(C)
Isopoda									
Gnorimosphaeroma oregonensis					X	X	X	X	R
Amphipoda									
Eogammarus (=*Anisogammarus*) *confervicolus*	X		X	X	X	X	X	X	C
Ampithoe valida	?X			X			X		R

Table 2.5-2 Cont'd.

TAXA	Beak (1977)	Bawden et al. (1973)	Levings & Coustalin (1975)	McGreer (1976)	Northcote et al. (1976) (inbenthos)	Northcote (epibenthos)	Levings et al. (1978)	Levings (1980)^2	Abundance^1
Ampithoe humeralis		X							R
Corophium salmonis							X	X	R
C. insidiosum				X			X		C-(A)
C. ascherusicum							X		R
Corophium spp.	X		X		X	X	X	X	A
C. spinicorne				X					R
C. brevis				X					R
Paraphoxus sp.	X		X						R
Trichophoxus sp.					X	X			R
Eohaustorius washingtonianus			X						(C)
Mysidacea									
Neomysis mercedis			X		X	X		X	(C)
Decapoda									
Crangon franciscorum	X				X	X		X	R
Hemigrapsus oregonensis							X		R
Cancer magister (zoea)	X							X	(C)
(megalopa)								X	(C)
Ostracoda		X	X						(C)
Insecta									
Anisoptera						X			R
Ceratopogonidae						X			R
unident. dipteran						X			R

Table 2.5-2 Cont'd.

TAXA	Beak (1977)	Bawden et al. (1973)	Levings & Coustalin (1975)	McGreer (1976)	Northcote et al. (1976) (inbenthos)	Northcote (epibenthos)	Levings et al. (1978)	Levings (1980)[2]	Abundance[1]
Monodiamesa						X			R
Chironomus						X	X	X	(C)
Paracladopelma					X	X			R
Polypedilum					X	X			R
Strictochironomus						X			R
Dolichopodidae B							X		R
Tipulidae							X		R
SIPUNCULA									
Golfingia sp.							X		(C)
ECHIURA									
Nellobia *eusoma*				X					R

---

[1] Taxa are classified as rare (R), common (C) or abundant (A). Classes are somewhat subjective and based on abundance data in published reports. Taxa marked with an * are meiofaunal groups known to be abundant but inadequately

sampled due to the mesh size used. "Rare" taxa are those with a low frequency of occurrence (i.e. small proportion of samples contained them) and/or very low abundances (generally less than 1% by number of total collection by author). "Common" taxa had a higher frequency of occurrence and/or were present in higher desities (usually between 1 and 10%). "Abundant" taxa are those which may comprise over 10% of the total number collected. Taxa which were judged either common or abundant at a restricted number of sites are indicated by parentheses around the symbol.

[2] Levings (1980) sampled at the junction of Canoe Pass with Sea Reach. Only taxa which are also found closer to the proposed route are indicated in this column.

2.5.1.1 The Structure of the Benthic Community by "Zones"

The benthic environment of the proposed pipeline route may be divided into four "zones" or habitat types (Figure 1.3-1):

I	the marsh/mudflat
II	Canoe Pass (riverine)
III	the intertidal sandflat
IV	the slope (subtidal)

The benthic community in each of these zones will be described in some detail.

2.5.1.2 The Marsh/Mudflat

A total of 12 invertebrate taxa occurred at the "mudflat" sites (sediment grain size, Median diameter (Md) < 100 μm) - ROB1 & ROB2 of Levings and Coustalin (1975). Three taxa together comprised over 90% of the total numbers of individuals collected (Table 2.5-3). The invertebrates of the "mud" sites were numerically dominated by a single species, the small sabellid polychaete Manayunkia aestuarina (77.8% of total numbers; 14.9% of the total wet-weight biomass). In terms of major classes, the sites were polychaete-dominated (Table 2.5-4); polychaetes made up 88.7% of the community by numbers and 54.1% of the total community biomass (wet weight). The bivalve Macoma, while only 1.2% of the community by numbers, comprised the greatest proportion of the community biomass of any single taxon (42.3%).

2.5.1.3 Canoe Pass (Riverine)

(a) "inbenthos": a total of 25 invertebrate taxa were collected by grab samples of the benthos of Canoe Pass (Table 2.5-5) (Station 4 of Northcote et al. 1975). Five taxa together comprised 90% of the individuals collected (Table 2.5-6). The invertebrates of the "inbenthos" of Canoe Pass were numerically dominated by the amphipod Corophium and oligochaetes which together made up 75% of all individuals collected in grab samples. In terms of major classes, Canoe Pass was dominated by a combination of Crustacea and Oligochaetes (80.3% by number) (Table 2.5-7). The third most abundant species by number

Table 2.5-3 The dominant (in terms of numbers) invertebrate taxa of the "mud" sites of Levings and Coustalin (1975) - ROB1 and ROB2 (ranked in order of decreasing abundance).

Rank	Taxon	(Class)	Total Number	%	Cumulative %
1.	_Manayunkia_ _aestuarina_	(B)	2400	77.8	77.8
2.	Ostracoda	(D)	206	6.7	84.5
3.	_Amphicteis_ sp.	(B)	189	6.1	90.6
4.	_Nereis_ _limnicola_	(B)	100	3.2	93.8
5.	Oligochaeta	(C)	58	1.9	95.7
6.	_Eteone_ _longa_	(B)	45	1.5	97.2
7.	_Corophium_	(D)	40	1.3	98.4
8.	_Macoma_	(A)	36	1.2	99.6

Table 2.5-4 Percent composition of the benthic invertebrates at mudflat sites by class.

(Class)		Total Number	%	Cumulative %
A.	Bivalvia	37	1.2	1.2
B.	Polychaeta	2734	88.7	89.9
C.	Oligochaeta	58	1.9	91.8
D.	Crustacea	254	8.2	100.0
E.	Insecta	-	-	-
F.	Others	-	-	-

Table 2.5-5 Benthic community composition in Canoe Pass and on Roberts Bank.

	Canoe Pass				Roberts Bank			
Taxon	Benthic[1]		Epibenthic[2]		Mud[3]		Sand[4]	
	No.	%	No.	%	No.	%	No.	%
Nemertina	67	5.5	33	1.4	1	0.03	20	4.8
Nematoda	7	0.6	15	0.6				
Eteone	5	0.4	18	0.8	45	1.5	14	3.5
Nereis limnicola	19	1.5	14	0.6	100	3.2	13	3.1
Amphicteis sp.	1	0.1			189	6.1	1	0.2
Glycinde picta							1	0.2
Armandia brevis							1	0.2
Manayunkia aestuarina					2400	77.8		
Paraonis platybranchia							46	11.1
Pygospio elegans							3	0.7
Oligochaeta	388	31.7	31	1.3	58	1.9		
Macoma sp.	73	6.0	34	1.4	36	1.2	156	37.7
Musculus substriatus					1	0.03		
Daphnia	1	0.1	1	0.04				
Harpacticoida	1	0.1	591	25.3	4	0.1		
Calanoida	1	0.1	1	0.04				
Cyclopoida	1	0.1	10	0.4				
Neomysis mercedis	15	1.2	1024	43.8			1	0.2
Corophium	530	43.3	194	8.3	40	1.3	2	0.5
Eogammarus confervicolus	39	3.2	170	7.3			6	1.4
Trichophoxus	2	0.2	2	0.1				
Eohaustorius washingtonianus							117	28.3
Paraphoxus sp.							29	7.0
Tanais sp.					4	0.1		
Gnorimosphaeroma oregonensis	1	0.1	8	0.3				

Table 2.5-5 Cont'd.

Taxon	Canoe Pass				Roberts Bank			
	Benthic[1]		Epibenthic[2]		Mud[3]		Sand[4]	
	No.	%	No.	%	No.	%	No.	%
Crangon franciscorum	3	0.2	145	6.2				
Ostracoda					206	6.7	4	1.0
Anisoptera	1	0.1						
Ceratopogonidae	2	0.2						
Diptera	1	0.1						
Monodiamesa	12	1.0						
Chironomus	43	3.5						
Paracladopelma	2	0.2	1	0.04				
Polypedilum	3	0.2	1	0.04				
Strictochironomous	5	0.4						
Epibenthos of Canoe Pass only:								
Planaria			9	0.4				
Mytilus edulis			1	0.04				
Acanthomysis			29	1.2				
Cumella			1	0.04				
Caddisflies			2	0.1				
Crictopus			2	0.1				
TOTAL	1223		2338		8084		414	

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[1] Data are calculated from Northcote et al. (1976), Appendix 2 (Station 4). Tabulated values (No.) indicate total number of individuals captured by benthic grab samples obtained on 11 October 1972 (n = 5), 28 November

1972 (n = 5), 20 March 1973 (n = 5) and 28 August 1973 (n = 10); the tabulated values thus represent the total count/25 samples x 0.05 m^2 / sample = total number / 1.32 m^2.

[2] Data are calculated from Northcote et al. (1976), Appendix 7 (Station 4). Tabulated values (No.) indicate the total number of individuals captured in epibenthic net samples obtained on 28 November 1972 (n = 2), 30 March 1973 (n = 6), and 28 August 1973 (n = 6); tabulated values thus represent the total count / 14 samples x 4.9 m^2 / sample = total number / 68.6 m^2.

[3] Data are calculated from Levings and Coustalin (1975), Table 5 - Stations ROB1 and ROB2. Tabulated values (No.) indicate total number of individuals captured in quadrat samples (0.06 m^2 to a depth of 2 cm) obtained on 11 December 1973 (n = 2); tabulated values thus represent the total count / 2 samples x 0.06 m^2 / sample = total count / 0.12 m^2.

[4] Data are calculated from Levings and Coustalin (1975), Table 5 - Stations ROB3 -ROB18. Tabulated values (No.) indicate total number of individuals captured in quadrat samples (0.06 m^2 to a depth of 2 cm) obtained on 11 December 1973 (n = 8) and 10 December 1973 (n = 8); tabulated values thus represent the total count / 16 samples x 0.06 m^2 / sample = count / 0.96 m^2.

[5] % indicates total % by number of that taxon of all benthic or epibenthic individuals collected in habitat on all sampling dates.

Table 2.5-6 The dominant taxa (by numbers) of the Canoe Pass site of Northcote et al. (1976) - (Site 4) - "inbenthos"; ranked in order of decreasing abundance.

Rank	Taxon	(Class)	Total Number	%	Cumulative %
1.	Corophium	(D)	530	43.3	43.3
2.	Oligochaeta	(C)	388	31.7	75.0
3.	Macoma	(A)	73	6.0	81.0
4.	Nemertina	(F)	67	5.5	86.5
5.	Chironomus	(E)	43	3.5	90.0
6.	Eogammarus confervicolus	(D)	39	3.2	93.2
7.	Nereis limnicola	(B)	19	1.5	94.7
8.	Neomysis mercedis	(D)	15	1.2	95.9

Table 2.5-7 Percent composition of the "inbenthic" invertebrates of the Canoe Pass site by class.

(Class)		Total Number	%	Cumulative %
A.	Bivalvia	73	6.0	6.0
B.	Polychaeta	25	2.0	8.0
C.	Oligochaeta	388	31.7	39.7
D.	Crustacea	594	48.6	88.3
E.	Insecta	69	5.6	93.9
F.	Others	74	6.1	100.0

(Macoma sp.) was only 6.0% of the number of individuals collected, but it was the most abundant species in terms of biomass (Figure 4 in Northcote et al., 1976).

(b) "epibenthos": a total of 25 invertebrate taxa were identified from the "epibenthos" of Canoe Pass (Table 2.5-5). Five taxa together made up 90.9% of the fauna collected (by numbers) (Table 2.5-8). The invertebrates of the epibenthos were dominated by the mysid Neomysis mercedis (43.8%), in contrast to the "inbenthos" where this species was only 1.2% of the individuals collected. Large harpacticoids made up 25.3% overall of the total numbers, but of the 591 harpacticoids collected, 589 were from a single tow (from 1.2 m depth). In terms of major classes (Table 2.5-9), the epibenthos of Canoe Pass was dominated by Crustacea (93.1%). The largest contributor to epibenthic biomass was the shrimp Crangon franciscorum which was only 6.2% of the numbers collected.

Table 2.5-8 The dominant taxa (by numbers) in the Canoe Pass epibenthos - from site 4 of Northcote et al. (1976).

Rank	Taxon	(Class)	Total Number	%	Cumulative %
1.	*Neomysis mercedis*	(D)	1024	43.8	43.8
2.	Harpacticoida	(D)	591	25.3	69.1
3.	*Corophium*	(D)	194	8.3	77.4
4.	*Eogammarus confervicolus*	(D)	170	7.2	84.7
5.	*Crangon franciscorum*	(D)	145	6.2	90.9
6.	*Macoma*	(A)	34	1.4	92.3
7.	Nemertina	(F)	33	1.4	93.7
8.	Oligochaeta	(C)	31	1.3	95.0
9.	*Acanthomysis*	(D)	29	1.2	96.2

Table 2.5-9 Percent composition of the epibenthic invertebrates of Canoe Pass by class.

(Class)		Total Number	%	Cumulative %
A.	Bivalvia	35	1.5	1.5
B.	Polychaeta	33	1.4	2.9
C.	Oligochaeta	31	1.3	4.2
D.	Crustacea	2176	93.1	97.3
E.	Insecta	6	0.2	97.5
F.	Others	57	2.5	100.0

2.5.1.4 Intertidal Sandflat

A total of 15 invertebrate taxa were identified from shallow quadrat samples of the benthos of the sandflat (sediment grain size, Md > 175 µm) ROB3 - ROB18 of Levings and Coustalin (1975). Six taxa together comprised more than 90% of the individuals collected. The dominant taxa were the bivalve Macoma (37.7%) and the amphipod Eohaustorius washingtonianus (28.3%) (Table 2.5-10). Bivalves and Crustacea were equally abundant across the sandflat considered as a whole (Table 2.5-11). The patterns of occurrence will be considered in more detail in the following section.

2.5.1.5 Delta Slope

The nearest known survey of the benthos below LLW on the delta was reported by Beak (1977). Six stations numbered A6 - All north of the Roberts Bank coalport, from LLW to a depth of 36.6m, were sampled with a Ponar Grab. Faunal lists and counts are given in Beak (1977) Annex B-2, Tables B-2-1 to B-2-8. Because these sites were not located in close proximity to the proposed route (approximately 5.5 km to the south) we will not consider the Beak data in the same detail as we have done for the flats and Canoe Pass. General patterns of distribution should, however, be similar. The sediments on the foreslope along A transect were largely sands with a zone of silts occurring at a depth of 12.2 m (Beak 1977, Table B-15).

All but one (Eohaustorius washingtonianus) of the five invertebrate taxa found on the outer sand flats (sites 12 - 18) by Levings and Coustalin (1975) also occurred below the LLW line along transect A. In all, 15 of the taxa recorded in Canoe Pass and on the intertidal flats also occurred on the foreslope (see Table 2.5-2).

The gross characteristics of the benthos of the four zones through which the proposed pipeline route passes are summarized in Table 2.5-12 and graphically in Figure 2.5-2. As emphasized earlier, comparison of the results of surveys by different authors must be made with caution since neither the times of sampling nor the sampling methods were uniform. The mud and sandflat sites represent winter densities, the foreslope sites represent summer densities and the Canoe

Table 2.5-10 The dominant taxa (by number) in the benthos of the sandflat portion of Roberts Bank (Levings and Coustalin, 1975 - ROB3 to ROB18).

Rank	Taxon	(Class)	Total Number	%	Cumulative %
1.	Macoma sp.	(A)	156	37.7	37.7
2.	Eohaustorius washingtonianus	(D)	117	28.3	66.0
3.	Paraonis platybranchia	(B)	46	11.1	77.1
4.	Paraphoxus sp.	(B)	29	7.0	84.1
5.	Nemertina	(F)	20	4.8	88.9
6.	Eteona longa	(B)	14	3.4	92.3
7.	Nereis limnicola	(B)	13	3.1	95.4

Table 2.5-11 Percent composition of the sandflat benthos by class.

(Class)		Total Number	%	Cumulative %
A.	Bivalvia	156	37.7	37.7
B.	Polychaeta	79	19.1	56.8
C.	Oligochaeta	-	-	
D.	Crustacea	159	38.4	95.2
E.	Insecta	-	-	
F.	Others	20	4.8	100.0

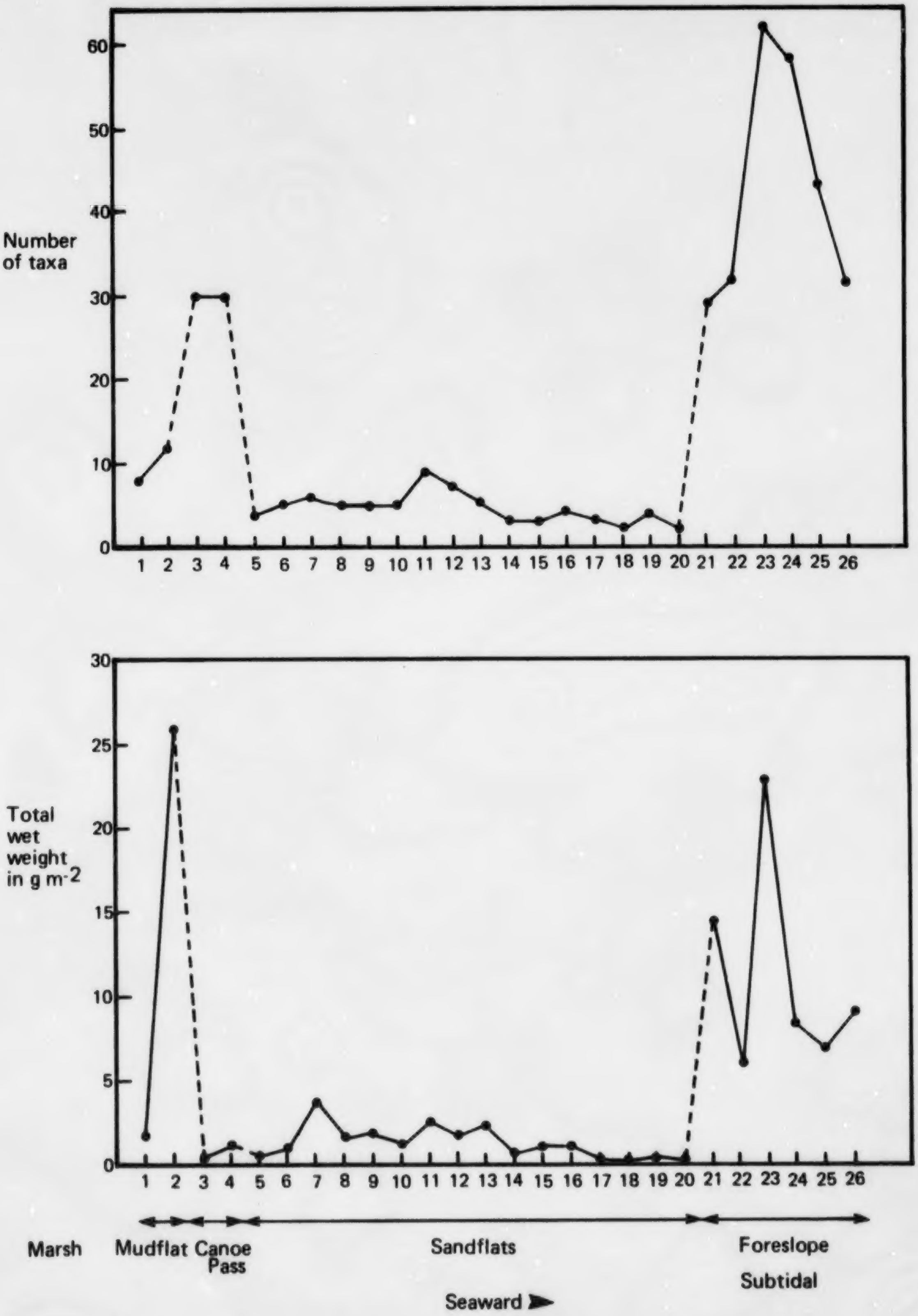
Table 2.5-12 Summary of benthic invertebrate data from several sources through habitats equivalent to 4 zones in the path of the proposed pipeline route.

	Zone	Station	Total Wet wt. (g/m^2)	Total No./m^2	Elevation (m)	Md or (% Sand)	#Taxa
		ROB 1	1.60	13 888	+ 2.74	88	8
I	Mudflat	ROB 2	25.97	35 648	+ 3.04	23	12
II	Riverine	St. 4e	0.45	35	-.8 to-4.6	sand to	25
		St. 4i	1.10	1 000	-1. to-5.5	mud	25
III	Sandflat	ROB 3	0.57	512	+ 2.74	205	4
		ROB 4	0.95	432	+ 2.74	198	5
		ROB 5	3.80	592	+ 2.13	185	6
		ROB 6	1.44	544	+ 0.92	215	5
		ROB 7	1.92	512	+ 0.91	224	5
		ROB 8	1.12	352	+ 1.52	231	5
		ROB 9	2.14	544	+ 1.52	200	9
		ROB 10	1.79	640	+ 0.91	200	7
		ROB 11	2.28	528	+ 0.91	177	5
		ROB 12	0.44	528	+ 0.91	182	3
		ROB 13	1.12	480	+ 0.91	188	3
		ROB 14	0.98	464	+ 0.91	210	4
		ROB 15	0.17	64	+ 0.91	241	3
		ROB 16	0.25	144	+ 0.91	200	2
		ROB 17	0.36	144	+ 0.30	180	4
		ROB 18	0.18	128	+ 0.30	180	2
IV	Foreslope	A6	14.05	7 062	0	(93.9)	29
		A7	5.80	3 635	- 4.6	(74.1)	32
		A8	22.87	5 361	-12.2	(47.3)	61
		A9	8.19	3 011	-19.8	(90.4)	58
		A10	6.68	2 608	-27.4	(79.2)	43
		A11	9.07	2 060	-36.6	(96.7)	30

Md = median diameter

Figure 2.5–2

Summary graph of trends in benthic biomass and number of taxa across proposed pipeline route (site locations and data sources are listed in Table 2.5-12).



Pass sites represent an approximate annual mean. Moreover, coarser mesh sizes were used in Canoe Pass - 0.61 mm for inbenthos and 1.09 mm for the epibenthos. The loss of numbers of individuals retained on a 0.5 mm mesh but passing through the coarser meshes may be as great as 12% (0.61 mm) and 45% (1.09 mm) (Holme and McIntyre, 1971). Lastly, the grabs used in the "subtidal" sample further into the sediment than the 2 cm sampled in the intertidal and may account for some (unknown) elevation of numbers, biomass and/or number of taxa counted.

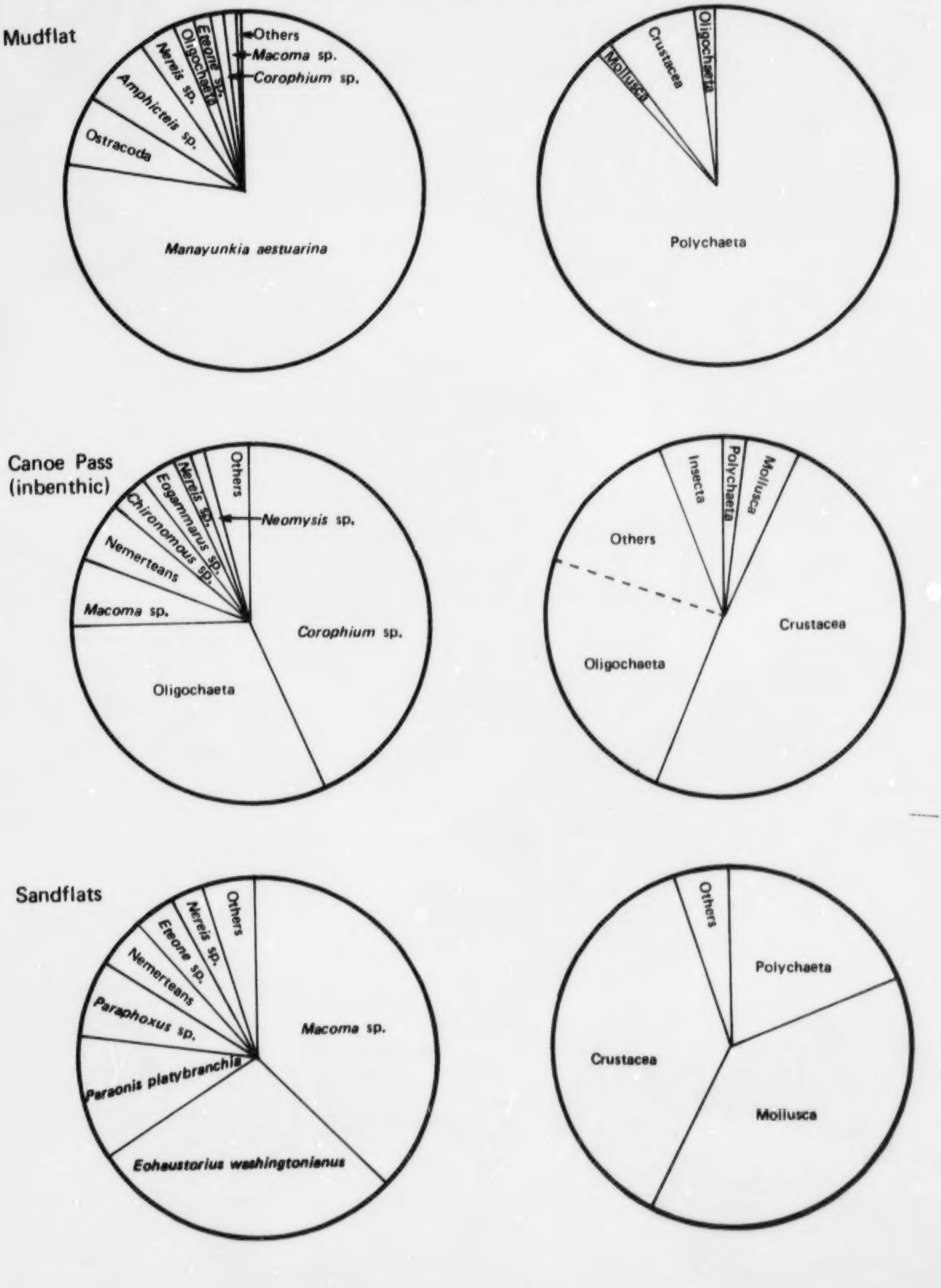
In spite of these differences in methodologies, some broad generalizations regarding the nature of the benthic communities may be drawn. The maximum density of individuals occurred in the mudflat adjacent to the marsh (1.4 to 3.5 x $10^4/m^2$). Densities of invertebrates (epi- and inbenthos) in Canoe Pass were approximately one order of magnitude lower (about $10^3/m^2$). Abundances on the sandflat were approximately 50% of those in Canoe Pass (on the order of 0.5 x $10^3/m^2$), with lowest densities occurring on the outer flats at elevations less than +1.0m. Much higher densities were observed on the foreslope (2 to 7 x $10^3/m^2$). Biomass (wet weight) (Figure 2.5-2) followed approximately the same pattern with maxima occurring in muddy sediments off the marsh (ROB2 -25.97 g/m^2) and subtidally at 12.2m depth (A8 - 22.87 g/m^2). Biomass was generally low (max = 3.8 g/m^2) in Canoe Pass and on the sandflats where it decreased toward the delta edge.

The highest numbers of taxa occurred at subtidal sites in Canoe Pass (n = 25) and on the delta foreslops (n = 29 to 61). The number of taxa present at the mud and sandflat sites was generally low (2 to 12) compared with the physically less variable subtidal sites.

The composition of the inbenthic communities of the intertidal flats and Canoe Pass are compared graphically in Figure 2.5-3 (from data in Tables 2.5-6 to 2.5-11). On the whole, the mudflat is qualitatively the least diverse community with over 75% of all individuals belonging to the species Manayunkia aestuarina, a small, tube dwelling, filter feeding polychaete. The inbenthos of Canoe Pass is dominated by two taxa: the amphipods Corophium spp. and oligochaetes. Corophium spp. were most abundant at shallow, muddy sites sampled in August and October while oligochaetes were generally restricted to deeper, muddy sites sampled in October and November (Northcote et al., 1976). Highest densities of Macoma in Canoe Pass were found in the spring.

Figure 2.5-3

Proportionate contribution (by number) of benthic taxa in the mudflat, riverine and sandflats habitats; (left) by species and (right) by major classes. Data are from Tables 2.5 - 3, 2.5 - 4, 2.5 - 6, 2.5 - 7, 2.5 - 10, and 2.5 - 11.

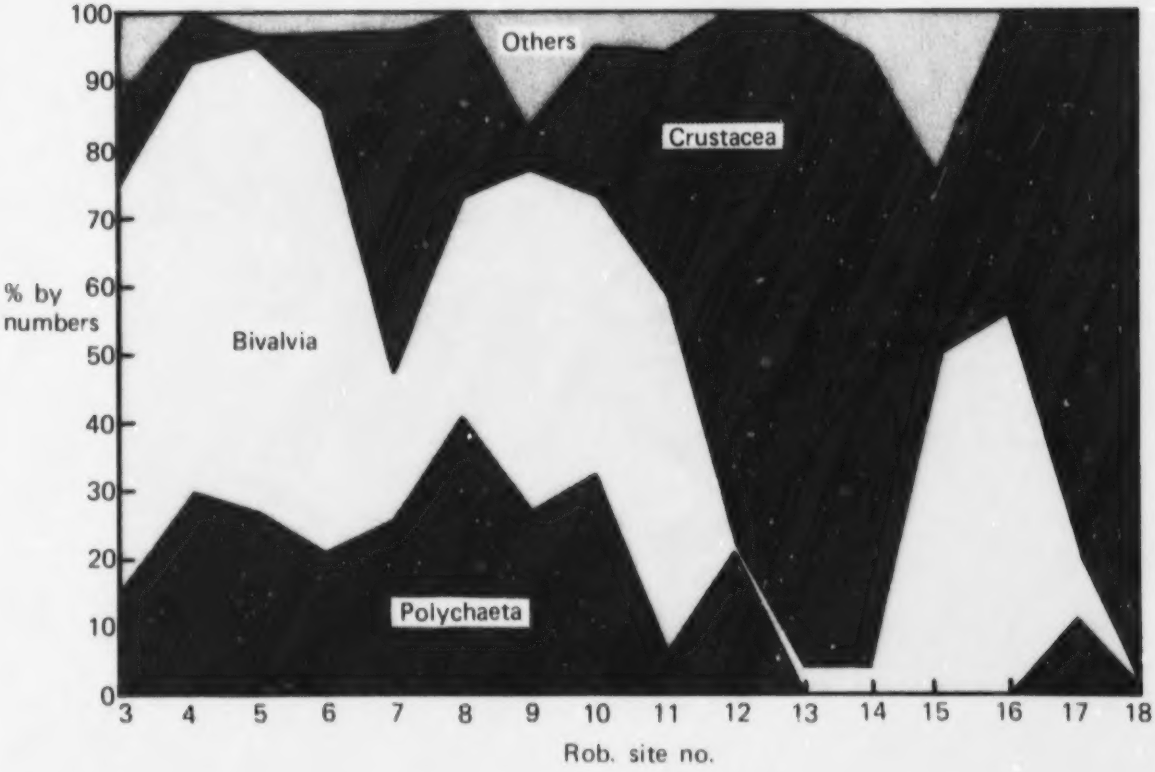


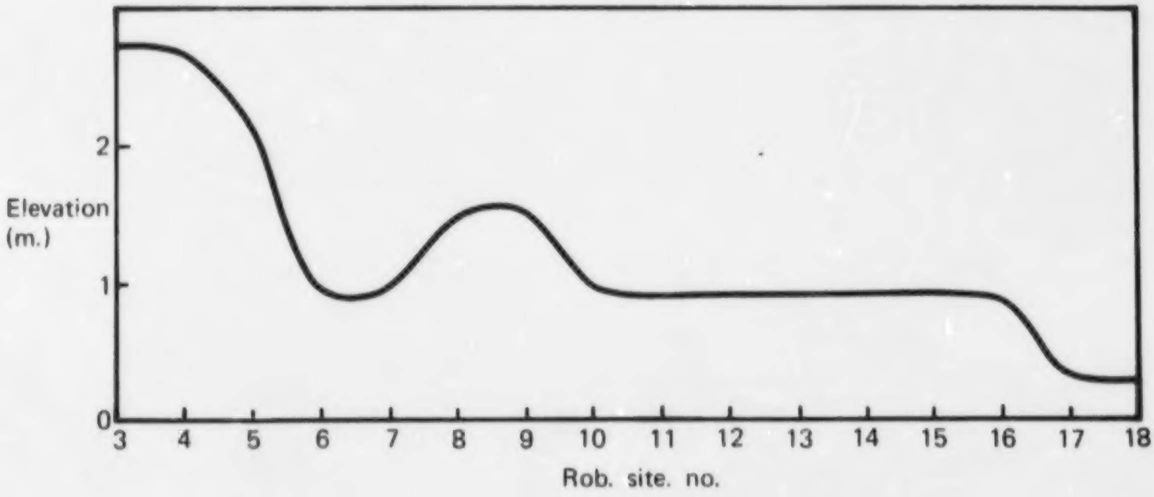
The most abundant taxa on the sandflat were the deposit feeding bivalve Macoma, the amphipod Eohaustorius washingtonianus and the deposit feeding polychaete Paraonis platybranchia. The sandflat, although relatively featureless and uniform in sediment composition (Md = 177 - 241 µm) covers a large area and includes a broad range of tidal heights, and therefore, exposures. The distribution of benthic invertebrates across this zone reflects this heterogeneity (Figure 2.5-4). The inner flats, with the exception of site 7 are dominated by bivalves (Macoma) and ploychaetes. Crustacea become abundant beyond site 10 (+0.91m) and dominate to the slope edge except for two Macoma - dominated sites on the outer banks (ROB15-16).

Comprehensive information on the food webs of the intertidal is sadly lacking. However, given the generality that juvenile salmonids and other small, estuarine fish feed mainly on small crustacea and insects (Levy et al., 1979), the benthos of Canoe Pass and the marsh is most likely to favour the development of a fish food web. On the other hand, as suggested by Levings and Coustalin (1975) the high proportion of Macoma in the benthos of the sandflats favours the production of the commercial crab, Cancer magister.

Figure 2.5-4

Percent composition of benthic communities (by number) across the sandflats (calculated from Levings and Coustalin, 1975).





2.5.1.6 Factors Affecting Distribution

The main factors controlling the distribution of the benthic invertebrates on Roberts Bank are grain size of the substrate, elevation (or depth, in the subtidal) and "salinity". Maximum biomass on the banks occurred at sites +2.5 to +3.0m above chart datum (-1.5 to 0 Geodetic) on muddy substrates with a Md = 0.05 mm (Levings and Coustalin, 1975). In the riverine habitat, numbers and biomass were also higher on finer substrates and tended also to be highest below 3m depth (Northcote et al., 1976). The benthic community of the slope was richer in both abundance and diversity than the sandflat counterpart, probably because the subtidal is a less stressful and more saline habitat (Beak, 1977).

Seasonal Effects

The surveys on which this report is based are too restricted in time to evaluate the seasonality of the benthic communities of Roberts Bank. Large changes in abundance of many taxa are evident in the data from Canoe Pass if the four months sampled are compared. For example, although all samples from October and November contained oligochaetes, only one of ten grabs collected in August and none of five samples from March did. Similarly, the other dominant taxon, *Corophium*, was extremely rare in both November and March.

Levings et al. (1978) studied the seasonality of the benthos at a pair of sites, A and B in the mudflat at +3.0m (see Figure 2.5-1 for location) by sampling monthly from June 1975 to April 1976. Statistically significant (from analysis of variance) seasonal fluctuations in abundance were observed, with two peaks of approximately 4.1×10^5 individuals/m^2, one in October, the other in February. *Manayunkia aestuarina* abundances peaked in winter (October and February) while *Corophium* spp. peaked in summer. *Macoma* was never very abundant at the site and its densities remained relatively constant through the year.

2.5.1.7 Dungeness Crab (Cancer magister)

The Dungeness crab Cancer magister supports an important fishery in B. C. waters with a total annual landed value of 1.04 (1976) to 2.86 (1980) million dollars between 1974 and 1980[1] (Table 2.5-13). Total landings of crab by area for the past seven years are given in Table 2.5-13. Between 1974 and 1980, the total Fraser catch fluctuated between a low of 14.8% of the B. C. total (1980) and a high of 42.6% (1976), with the actual landed weight from the Fraser ranging from 237 (1974) to 424 (1976) metric tonnes. The total B. C. catch was also variable (Figure 2.5-5) over the period 1965 - 1980. with generally higher catches through the 1960's and lower, less variable total catches through the 1970's. 1980 was marked by a 44% increase in total catch over the previous year, mostly accounted for by an 80% increase in the North Coast catch (Table 2.5-13).

Life History[2]

Cancer magister ranges from Unalaska, Alaska to Magdalena Bay, Mexico and is fished commercially from Alaska to California. In B. C. crabs occur mostly on sandy, shallow bottoms. Crabs larger than 16.5 cm (6.5 inches) carapace width can be fished legally. Females rarely attain legal width and so mainly males are fished; males may reach a width of 23 cm (9 inches).

Through the course of a season crabs move between deeper waters where they overwinter and shallow subtidal and lower intertidal sandflats where they feed and mate in summer (MacKay, 1942; Butler, 1951; Secter, 1979). Crabs are carnivores, feeding on small crustacea (shrimps, small crabs, barnacles, amphipods, isopods, etc.), molluscs and worms (MacKay, 1942). On the outer sand flats of Roberts Bank, their preferred food may be Macoma balthica (Levings and Coustalin, 1975).

Because the crab has a hard outer shell, the "exoskeleton", this exoskeleton must be shed, "moulted", periodically in order for the crab to grow. Following

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[1] Government of Canada, Dept. of Fisheries and Oceans. 1974-1980. Annual Summaries of British Columbia Catch Statistics.

[2] Summarized from MacKay (1942) and Butler (1951, 1956).

Table 2.5-13 Total crab landings (metric tonnes) by area (from: Annual Summaries of British Columbia Catch Statistics).

Area	1974	1975	1976	1977	1978	1979	1980
North Coast	505	441	307	420	481	558	1006
South Coast	393	383	264	302	338	374	443
Fraser[1]	237	316	424	308	357	247	252
Total	1135	1140	995	1030	1176	1179	1701
% Fraser	20.9	27.7	42.6	29.9	30.4	20.9	14.8
Total Landed Value $'000	1317	1435	1044	1190	1802	2267	2865

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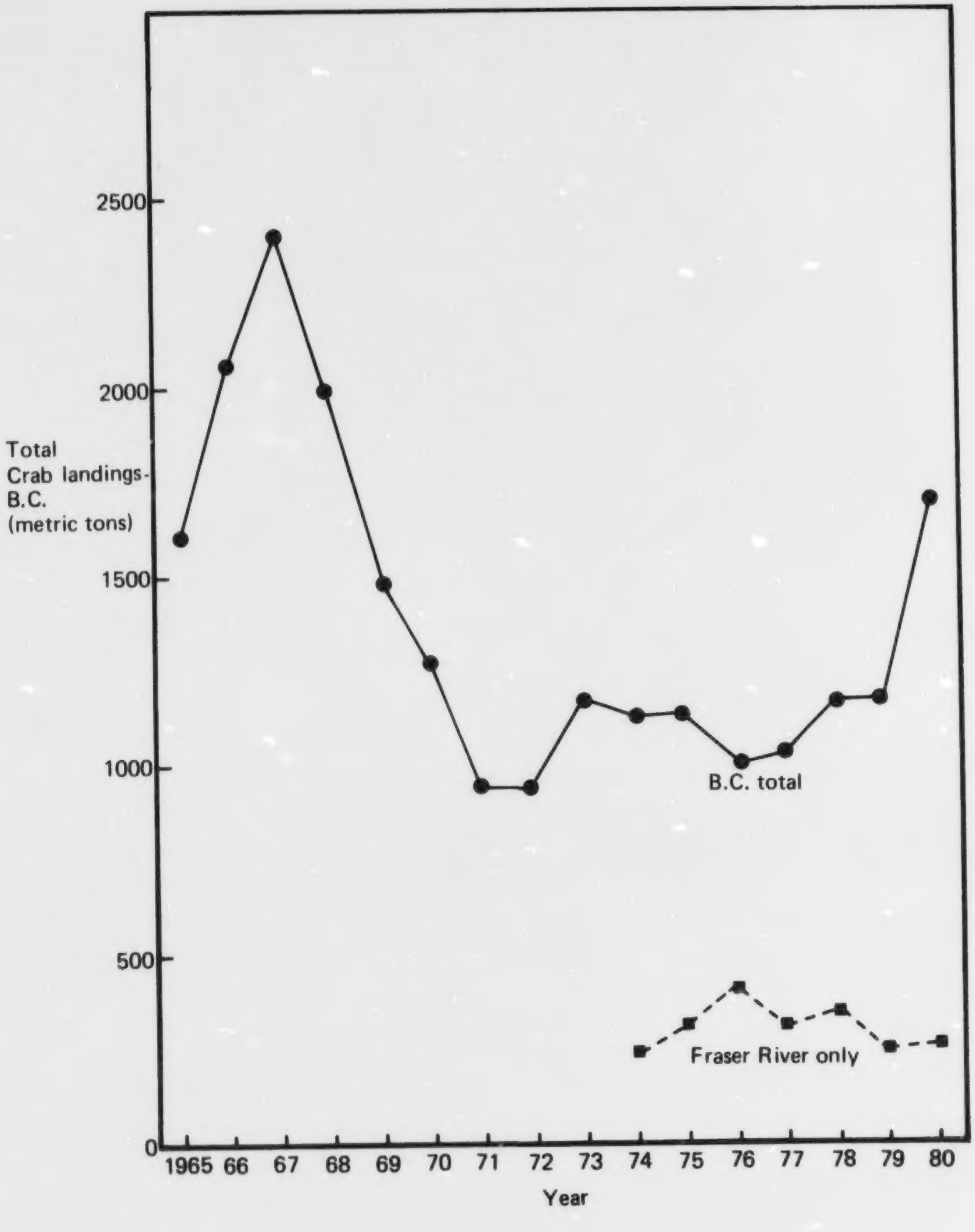
[1] Fraser area includes River, Point Grey/Sturgeon, Boundary Bay, Roberts Bank and Plume area.

Figure 2.5–5

British Columbia Crab landings from 1965 - 1980 (data from Annual Summaries of British Columbia Catch Statistics, 1974 - 1980).



moulting, the crab is soft and therefore vulnerable to damage for a period of up to two weeks (MacKay, 1942). For this reason, a "soft-shell closure" is set by the federal fisheries department in order to protect legal sized male crabs. During moulting individuals generally remain buried in sediment or under vegetation. Mature crabs moult only once a year and it is during this time (when the females are soft) that mating must occur (between a newly moulted female and an unmoulted male). Mating in southern B. C. can occur from April to September. The spermatazoa remain viable in the female for months after fertilization occurs. Fertilized eggs are extruded by the female in late September/early October and attached to her abdominal appendages where they are carried for approximately six months. Free-swimming larvae are hatched in March and April (MacKay, 1942; Butler, 1956).

The larval stages of the crab are planktonic (Figure 2.5-6). While in the plankton, crabs moult through several larval stages, beginning with the protozea, several zoeal stages and finally into the megalopa stage at which time they are approximately 2.5 mm wide (MacKay, 1942) and have begun to resemble adult crabs. The small post-larvae settle from the plankton onto shallow (< 9 m) sand bottoms (Butler, 1956) where they are often found associated with eelgrass or drift algae just beyond the surf-zone. Year-to-year fluctuations in the numbers of post-larvae entering the benthic population are mostly due to environmental factors acting on the planktonic phases (Butler, 1956).

Levings (1980) captured both zoea and megalopa stages in net and pump samples of plankton obtained over the Roberts Bank borrow pit. Densities of zoea peaked in May and the megalopa first appeared in small densities in July, with higher densities occurring in late August (Figure 2.5-7). The presence of megalopa in epibenthic samples from Roberts Bank in July and August, accompanied by a large drop in the number of zoea suggests that settlement in that area occurs in late summer which is in agreement with Butler's (1956) and MacKay's (1942) observations.

Growth of the early post-larval stages is rapid, with several stages being passed before the onset of cold weather. Small crabs seem to overwinter buried to about 10 cm depth on the sand flats. In Boundary Bay they may reach a density of 100 - 150/m^2 (MacKay, 1942). Most crabs become sexually mature in their

Figure 2.5–6

Diagram to illustrate the life history of the crab; from MacKay (1942).

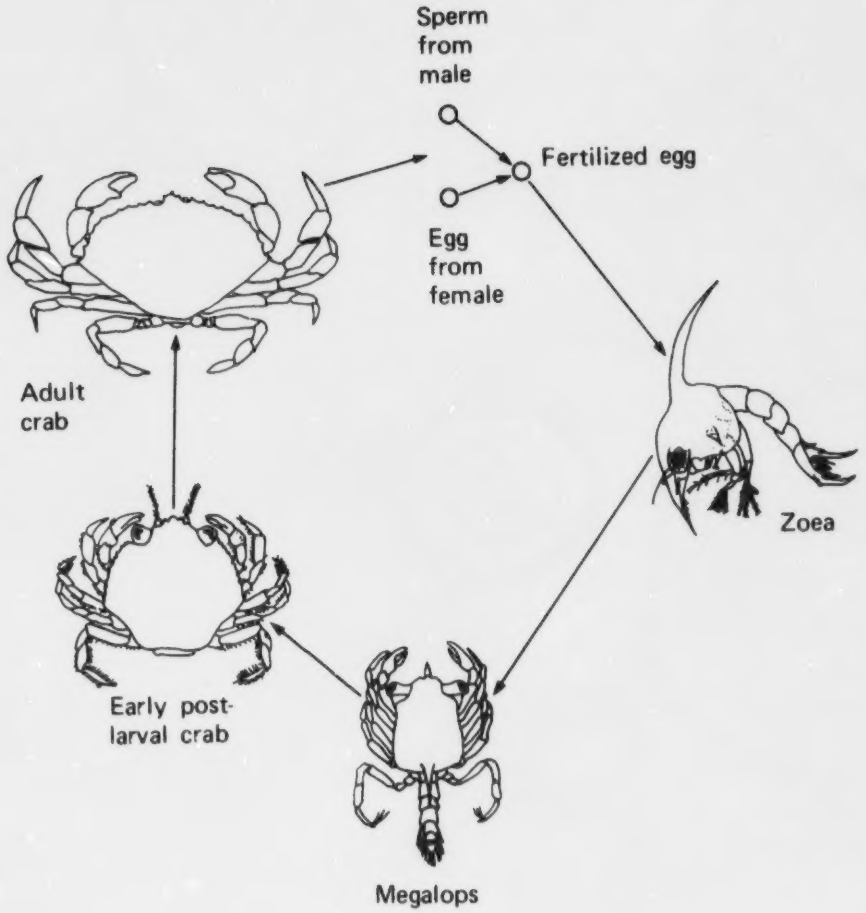
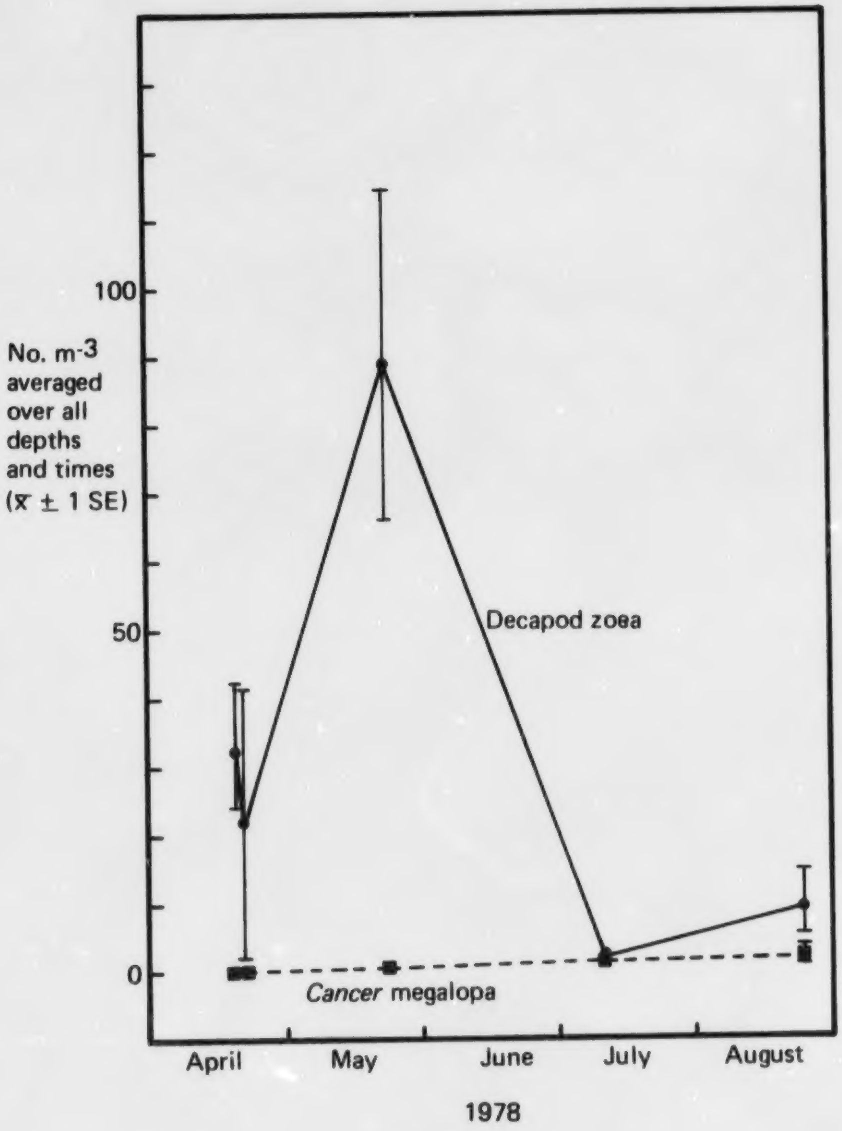

Sperm from male
Fertilized egg
Egg from female
Adult crab
Zoea
Early post-larval crab
Megalops

Figure 2.5-7

Seasonal occurence of *Cancer* megalopa and decapod zoea (from Levings, 1980; after Table II).
Roberts Bank Borrow pit site net and pump sampler (*Cancer* megalopa maximum = 13.2 m^{-3}).



fourth year after which moulting occurs once a year. Males reach edible size in the seventh or eighth year; eight years is the average longevity (in Boundary Bay) (MacKay, 1942).

The seasonal migration patterns of adult crabs were described by MacKay (1942) from tagging experiments in Boundary Bay in 1930-31 and in greater detail by Butler (1951). More recently (1979), tagging experiments were carried out on the crab populations of the intercauseway area on Roberts Bank although only preliminary results are available. Two generalities regarding the behavior of Cancer magister may tentatively be drawn from these studies:

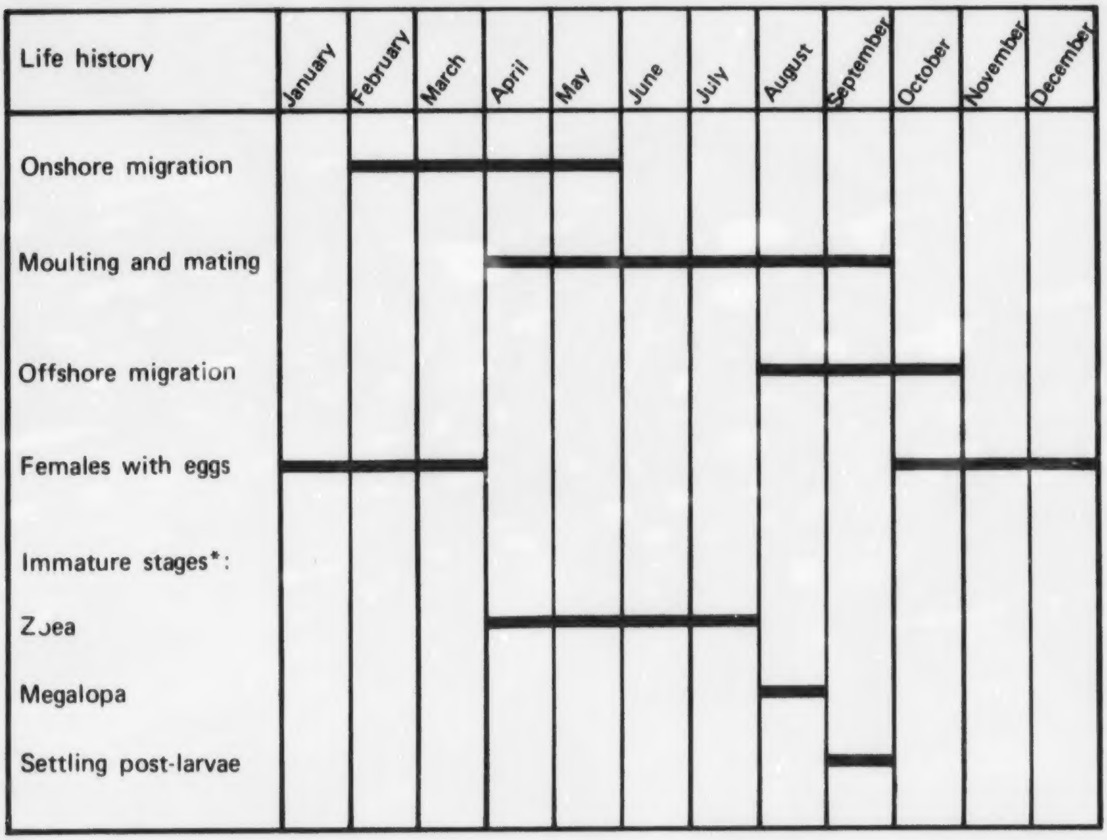
1. Crabs are highly motile and desplay aggressive behavior toward others of the species. Two consequences are that crabs are often segregated by size (Hillaby, 1979) and/or sex (MacKay, 1942) and they are "cosmopolitan in their behavior, migrating over wide areas either in search of food, mates, or to avoid more aggressive members of their own species." (Hillaby, 1979).

2. Crabs migrate seasonally. From tagging experiments off the north-east coast of Graham Island in the Queen Charlottes, Butler (1951) described a seasonal migration pattern. Tagged adults released in May and June six miles (10 km) offshore were recovered one mile (1.6 km) offshore in July and August. Crabs moved into deeper waters as the season advanced, with some tags recovered 12 miles (19 km) offshore by American vessels in September and October. While most tagged crabs were recovered in the same general area where they were tagged, one animal had migrated 33 miles (53 Km) in a period of 48 days. Hillaby (1979) noted an increase in average carapace width of the inter-causeway crab population between February and May suggesting that larger female crabs move to into the inter-causeway area in spring, possibly to breed.

   The probable seasonal patterns of the Dungeness crab in the Roberts Bank study area are summarized in Figure 2.5-8.

Figure 2.5-8

Seasonality of Dungeness crab in coastal B.C. (information compiled from: Hillaby, 1979; MacKay, 1942; Levings, 1980; Butler, 1956).



*Examples illustrated in Figure 2.5 - 6

2.5.2 Pipeline Route

Benthic samples were collected on 3 June 1981 during a general helicopter reconnaissance of the proposed pipeline route in order to corroborate our analyses of literature results. Samples were collected at four sites along the route: No. 1 north of dolphin #2 (site DOL2), No. 2 north of dolphin #3 (DOL3), No. 3 north of dolphin #4 (DOL4) and No. 4 at the bank edge (Bank Edge). These sites are located in Figure 2.5-1. At each site duplicate samples for quantitative estimation of densities of macrobenthos were collected: the sediment within a 0.08 m^2 quadrat was scraped to a depth of 4 to 5cm. Samples were bagged, returned to the laboratory and frozen. Prior to sorting, sediment samples were thawed and passed through a 0.5mm mesh. All material retained was fixed in 10% formalin. The fauna (=macrobenthos) retained was picked from the larger sediment and detrital particles retained on the mesh, sorted to major taxa, counted and finally preserved in 10% formalin.

Densities of the macrobenthos (number$\cdot m^{-2}$) were calculated for each quadrat individually; the data are presented in Table 2.5-14. Although we sampled fewer stations, patterns of meiobenthic distributions we observed were similar to those described by Levings and Coustalin (1975) in the following respects:

1. The macrobenthos across the sandflats were neither diverse nor (with the exception of site DOL4) very abundant.

2. The dominant taxon, in terms of numbers, was the bivalve mollusc, Macoma balthica, which comprised 74.9% of all individuals collected in our samples (37.7% of ROB3-ROB18).

3. Crustacea (mysids and amphipods) dominated at our bank edge site and at Levings and Coustalin's sites ROB17 and ROB18.

The distribution patterns described by Levings and Coustalin differ in three respects from our observations:

1. Polychaetes were not abundant in any of our samples but made up 5-40% of the individuals collected from inner and mid-bank sites (ROB3-ROB11) by Levings and Coustalin.

Table 2.5-14 · Number of individuals $\cdot m^{-2}$ and taxonomic composition of duplicate quadrat samples obtained from 4 sites along the proposed pipeline route on 3 June 1981. (number$\cdot m^{-2}$=count/0.08m^2 quadrat x 12.2; rounded to nearest whole number). For site locations see Figure 2.5-1.

SITE TAXON	DOL2		DOL3		DOL4		Bank Edge	
	a	b	a	b	a	b	a	b
NEMERTINA	12	-	-	-	-	-	-	-
ANNELIDA								
Polychaeta	-	-	12	-	-	25	-	-
MOLLUSCA								
Macoma balthica	125	75	37	175	1437	1612	-	25
ARTHROPODA								
Amphipoda								
Eogammarus confervicolus[1]	-	-	-	-	37	25	12	25
Corophium sp.	700	212	12	12	-	37	-	-
Mysidacea	-	-	-	-	-	-	37	12
TOTAL	837	287	61	187	1474	1699	49	62

[1] The identity of this species is in doubt and awaits expert confirmation.

2. High numbers of the amphipod Corophium sp. were found at our innermost site (DOL2); comparable ROB sites (ROB2, ROB3) were dominated by Macoma.

3. The zone of maximum bivalve densities occurs far lower in the intertidal in our samples (maximum at DOL4) than on the ROB transect (maximum at ROB2).

Some differences in the results of the two surveys are to be expected due to differences in sampling depth (we sampled to 4-5cm; Levings and Coustalin to 2cm). The most important factor, however, is probably season of sampling, since Levings and Coustalin's samples represent winter distributions (10-11 December) while our represent summer distributions. The distribution of Eogammarus confervicolus, for example, changes seasonally from a generally mid- to high intertidal pattern on southern Roberts Bank in winter to include lower intertidal sites in summer, particularly in the vicinity of Canoe Pass (Pomery and Levings, 1980). Shifting distribution patterns were linked to seasonal shifts in the abundance of cover, notably sedge (Carex lyngbyei) debris. The high density of Macoma balthica we observed on the sandflat at site DOL4 (mean ± 1 S.E. = $1524.5 \pm 87.5 \cdot m^{-2}$, n=2) compared with sites ROB8-ROB11 ($228 \pm 38.8\ m^{-2}$, n=4) may also be due to seasonal recruitment effects. All 115 individuals collected in sample DOL4a were measured. The smallest individual was 1.0mm long, the largest was 5.0mm long (mean=2.23 ± 0.079mm, n=115). On Roberts Bank, individuals less than 8mm long are less than one year old, thus the entire sample population consisted of newly settled individuals (McGreer, 1979). Maximum recruitment of settling spat occurs on Roberts Bank in February and March (McGreer, 1979). Older individuals (up to 9mm long) were found at our higher intertidal sites. Seasonal fluctuations may also be the reason for the lower polychaete numbers observed in our summer samples.

2.6 Fishery Resources

The 38 species of fish which use the lower reaches of the Fraser River during part of their life cycle may be divided into three groups according to what portion of their life history they spend in the estuary:

1. Migratory: species which pass through or are resident in the estuary for a short period of their life history.

2. Semi-Migratory: species which undergo periodic movements in the lower river, whether they reside in the river or adjacent waters.

3. Non-Migratory: species which pass entire life cycle in the lower river and/or associated waterways.

Extensive reviews and summaries of the existing literature on the biology and ecology of these fish species are available in Hart (1973), Hoos and Packman (1974), Northcote (1974), Beak (1977) and Northcote et al. (1978). Three especially significant publications concerning fish use of the estuary have appeared since these reviews were published: Levy et al. (1979), Greer et al. (1980) and Levy and Northcote (1981). The information to be presented below was derived primarily from these sources.

Migratory Species

The 14 migratory fish species listed from the Fraser River by Northcote (1974) are:

Salmon (*Oncorhynchus*) - Pink (*O. gorbuscha*)
Chum (*O. keta*)
Chinook (*O. tshawytsha*)
Coho (*O. kisutch*)
Sockeye (*O. nerka*)

Eulachon (*Thaleichthys pacificus*)
Longfin smelt (*Spirinchus thaleichthys*)
Surf smelt (*Hypomesus pretiosus*)
Coastal cut-throat trout (*Salmo clarki clarki*)
Steelhead trout (*Salmo gairdneri*)
Pacific lamprey (*Entosphenus tridentatus*)
River lamprey (*Lampetra ayresi*)
American shad (*Alosa sapidissima*)
Threespine stickleback (*Gasterosteus aculeatus*)

Four of these migratory species, chum, chinook, sockeye and threespine stickleback were captured by low tide beach seining in the drainage channels in the Canoe sector of Roberts Bank on 1 May and 12 July 1979, but comprised only 4.2% by number of all fish caught in that sector (Greer et al., 1980).

Migratory fish may pass through the Fraser Estuary at least twice during their lives. The greatest numbers do so as juveniles in transit from freshwater spawning grounds to coastal of oceanic feeding grounds. Those which survive the return journey to the spawning grounds will pass through again as adults on their way upstream. The importance of the estuarine habitat to juvenile migratory fish until recently, has been poorly understood (Dorcey et al., 1978). Although over three hundred million juvenile salmonids migrate into the estuary in certain years (Northcote, 1974) the first attempt to determine such vital factors as residence time, feeding patterns and spatial distributions while in the estuary was not made until the early 1970's (Dunford, 1975). Dunford sampled slough, side channel and marsh habitats in the North Arm (Swishwash and Sea Islands) and South Arm (Duck-Barber-Woodward Island complex) by beach seining and caught high numbers of juvenile chum and chinook. Maximum numbers of both species were captured in late April. Chinook occurred in the habitat until late July and appeared to grow during this period while chum appeared to vacate the marshes by June. While chinook and chum juveniles fed on many of the same prey items, Dunford showed that their diets diverged, particularly in the size of prey obtained (with chum eating small harpacticoid copepods and insects and the larger chinooks feeding on larger prey such as Neomysis). Chironomid (insect) pupae and Daphnia were the "preferred" prey of both salmonid species when available. Feeding by both species was highly variable both spatially and temporally although, in general, Dunford concluded that chinook were more "benthic oriented" and chum more "pelagic oriented" in feeding habits.

The findings of Dunford (1975) clearly suggested a possibly critical role for the Fraser river marsh system in the early life history of chinook and chum salmon. The report of large numbers of juveniles in the estuary (Goodman, 1975) further supported this hypothesis. Several direct juvenile salmonid-estuarine marsh links have been postulated (Dorcey et al., 1978) and will be reviewed more fully below: juvenile salmonids may use the marshes as:

(a) temporary residence areas
(b) seawater acclimation areas
(c) rich feeding areas
(d) refugia from predators
(e) staging areas from which to begin seaward migrations

It should be clear from the observations made by Dunford (1975) and Goodman (1975) that not all juvenile salmonids make equal use of the marsh areas. Dorcey et al. (1978 - Table 1) suggested that chinook make high use of both inner and outer marsh/tidal flats, chum make moderate use of inner marshes and coho of the outer marshes. The evidence available to 1978 suggested low to very low use of the marshes by juvenile sockeye and pinks.

2.6.1 Life History and Estuarine Use Patterns of Salmonid Species

The five species of Pacific salmon are anadromous, that is, they spawn and pass the egg and larval stages in fresh water streams, migrate as juveniles to the sea and return as mature adults to spawn and die in fresh water. Within this general pattern the five salmon species differ in the age at which they migrate seaward, the time of year in which this migration occurs, estuarine residence times, ocean residence times and the timing of the return to the spawning streams. Substantial differences in trophic ecology during the period of estuarine residence have also been discovered. These facets of the life history of each species, insofar as they are known, will be reviewed. Special emphasis will be placed on existing site-specific data relevant to the proposed pipeline project. These sites include:

1. Roberts Bank -
    sub-area 4: Steveston Jetty to Canoe Pass
    sub-area 5: Canoe Pass to Westshore Terminals causeway (Goodman, 1975).

2. The Duck-Barber-Woodward Island marsh complex (Dunford, 1975).

3. Woodward Island tidal channels and Foreshore tidal channel (Westham Island, near Canoe Pass) (Levy et al., 1979).

4. Middle Roberts Bank - Sector Canoe Pass drainage (Greer et al., 1980).

5. Woodward Island (W1-W6), Barber Island (B1-B5) and Foreshore (F1-F2) (Westham Island) (Levy and Northcote, 1981).

2.6.2 Pink Salmon *Oncorhynchus gorbuscha* (Walbaum 1972)

Pinks are the most abundant of the five salmon species fished in B. C. waters, accounting for 41.4% of B. C. Salmon landings between 1971 and 1980[1] with a total landed value of 125.8 million dollars (compared with 952.1 million dollars for the salmon fishery as a whole). Pinks are not widely distributed in the Fraser system, and the Fraser stocks contributed less than 10% to the total B. C. landings in recent years (9.5% in 1975, 3.2% in 1977 and 1.0% in 1979).

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[1] Unless otherwise noted, all fisheries statistics are derived from Department of Fisheries and Oceans. Annual Summary of British Columbia Catch Statistics, 1974 - 1980 incl.

Life History

After approximately 18 months at sea, mature pinks en route to the spawning streams migrate through the Fraser between mid-August and mid-October in odd-numbered years (Northcote, 1974). Two peaks in the Fraser spawning run can be discerned, an early run (approximately 75% of the total) with a maximum in mid-September and a late run in late September/early October. The annual spawning escapement averaged 810,000 fish between 1957 and 1971. Pinks generally spawn in early autumn in stream gravels not far from walt water. Eggs hatch in early February and young emerge from the gravel in April and May (Hart, 1973). Fry immediately begin their migration seaward.

Estuarine Use

Due to the strong cyclic fluctuations of pink populations, fry pass downstream through the Fraser estuary only in even numbered years. Young pinks feed in shallow inshore waters during their first summer and migrate to deeper waters in September. Between April and June, pinks in the less saline waters off the Fraser feed mainly on copepods but by July, at which time they are approximately 10 cm long, they feed also on insects, Oikopleura, chaetognaths, amphipods, euphausids and small fish of a variety of species (Hart, 1973).

The use of the inner estuary by pink fry has only been recently demonstrated (Levy et al., 1979). Goodman (1975) found no pinks in samples from Roberts Bank taken in 1973-74. Dunford (1975) captured only 3 pink fry in 60 beach seine and 40 pole seine samples in the Duck - Barber - Woodward Island complex in 1973-74 and so concluded (p.28) that pinks make only "negligible" use of marsh habitats in the Fraser. With an improved sampling technique (tidal channel trap nets), Levy et al. (1979) caught a total of 17,900 pinks in the same marsh complex in 1978. Information for the remainder of the discussion of marsh use by pinks is drawn from Levy et al. (1979) and Levy and Northcote (1981).

In 1978 approximately 389 million pink fry (compared with 124 million chum and 43 million chinook) migrated down stream past Mission (Levy and Northcote, 1981) and began to arrive in the Woodward Island tidal channels in February. Maximum numbers (0.11 - 0.91 per m^2) were observed on 21 - 30 April. Densities fell off sharply in May and no fish were captured after 7 June.

Several lines of evidence led Levy et al. (1979) to conclude that residence time of pinks in the estuary is probably very short (on the order of hours to days). First, in mark recapture experiments, very few marked pinks were recaptured. Second, fry in the Woodward Island tidal channels showed no evidence of growth between March and May. Third, fry lengths in the estuary were similar to fry lengths at Mission, again indicating no significant growth in the estuary. Lastly, pink fry were the first to emigrate from dewatering tidal channels.

During the short time they reside in the Fraser marshes, juveniles feed but show no evidence of growth. Between March and May, 1978 the mean length of juveniles captured on Woodward Island for analysis of feeding was 33.5mm (n=50) (Levy et al., 1979). Harpacticoid copepods were their main food (49.8% by volume) followed by insects - mostly Diptera and chironomids (24%) and the amphipods Eogammarus (=Anisogrammarus) confervicolus (4.8%) and Corophium spinicorne (1.9%) (Levy et al., 1979 - Figure 16). A similar feeding pattern (i.e. predation on meiobenthic harpacticoid copepods) was described for pinks feeding in shallow, nearshore areas of Puget Sound by Kaczynski et al. (1973). It seems reasonable to conclude, then, that pink fry pause only briefly in the Fraser marshes en route to shallow coastal feeding grounds. While in the marshes they feed mainly on small, epibenthic/benthic crustacea - especially harpacticoid copepods and also insects.

2.6.3 Chum Salmon Oncorhynchus keta (Walbaum 1972)

Although catches have declined in recent years (Northcote, 1974), the chum salmon remains an important commercial species. Between 1971 and 1980 chum accounted for a total of 12.1% of all B. C. commercial salmon landings with a total value of 170.8 million dollars. The contribution of Fraser area[1] catches to the annual B. C. catch averaged 4.1% (range=0.8 - 9.4%) between 1974 and 1980. During the same period, catches showed a further decline over those recorded in the late 1960's. Between 1965 and 1969 the annual Fraser chum catch averaged 571,000 fish (Northcote, 1974) while between 1974 and 1980 the Fraser area catch averaged only 80,000 chum annually (from 8,000 in 1979 to 174,000 in 1976).

Life History

Chum salmon make the return migration to their spawning streams usually after 3 to 5 years at sea (some after only 2 years, some after as long as 7) (Hart, 1973). The latest of the Pacific salmon to spawn, chum migrate into the Fraser river system between late September and mid-January (Goodman, 1975). The run begins with a 1 to 4 week period of accumulation at the river mouth. There are two major peaks in the run; although the exact timing of the peaks varies from year to year, the first occurs from mid-October to early November and the second between mid-November and early December (Northcote, 1974). The spawning grounds are located primarily in the river and its tributaries below Hope. Spawning occur late in the year (Hart, 1973). Eggs hatch in early spring, and like the pinks, chum immediately begin the seaward migration. The fry feed on insect larvae as they progress downstream (Hart, 1973). The migration begins between early and mid-March, with peak numbers passing Mission in April to May.

Estuary Use

The use of estuarine marshes of the Fraser by chum fry was studied by Dunford (1975) and subsequently in greater detail by Levy et al. (1979) and Levy and Northcote (1981). In 1978, 124 million chum fry migrated downstream past Mission. Fry appeared in the marsh tidal channels as early as mid-February (Table B1 - Levy et al., 1979) although numbers did not begin to increase until 21 March.

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[1] Fraser area is Fisheries Service statistical area 29 which includes Pt. Grey, Sturgeon and Roberts Banks, Boundary Bay, the river plume in the Strait of Georgia and the river upstream to Mission.

Peak chum fry densities of 0.094 - 0.181 individuals/m^2 were recorded on Woodward Island between 21 April and 30 April (Table 3 in Levy et al., 1979). Chum fry were last captured in the marshes on June 20.

Over 100 million chum fry pass through the Fraser marshes each year. Unlike pink fry, chum appeared to pause in the marshes for a period of days to weeks, using these productive areas as rearing grounds (Levy and Northcote, 1981). The results of mark recapture experiments carried out by Levy et al. (1978) are summarized in Table 2.6-1. These indicate that a high proportion of the chum fry present in the marshes in May were resident for at least two tidal cycles and a substantial number (4.1%) were still resident after seven days. Unlike the pinks, chum fry increased in length during the period they spent in the marshes, although their rate of change in length was not as fast as that shown by chinooks. Similar growth rates were recorded by Dunford (1975).

Trophic Relationships

Goodman (1975) examined the gut contents of 293 chum fry from the South arm of the Fraser and found that 59% of the diet biomass consisted of freshwater and terrestrial invertebrates; *Eogammarus confervicolus* and chironomid larvae were the dominant prey.

Dunford (1975) studied the stomach contents of fry from marsh habitats. The food of chum fry varied somewhat through the seasons. In late March 1973 the prey consisted of chironomid pupae (65%), *Eogammarus confervicolus* (20%), *Corophium spinicorne* (10%), *Neomysis mercedis* (9.5%) and chironomid larvae (7%). Later in the season when increasing numbers of chinook fry were present in the habitat, chum shifted foods somewhat toward such smaller prey as harpacticoid copepods and cladocera.

The mean length of chum fry captured on Woodward Island between March and June and included in stomach contents analyses by Levy et al. (1979) was 42.6mm (n=50). Insect pupae were the main prey (55.6% by volume) followed by insect larvae and adults (11.9%), harpacticoid copepods (11.0%), *Eogammarus confervicolus* (6.6%), fish (3.3%) and *Corophium spinicorne* (2.1%) (Levy et al., 1979 - Figure 15). Further analyses of diets in 1979 (reported in Levy and Northcote, 1981) indicated

Table 2.6-1 Summary of mark recapture experiments conductd in marsh tidal channels during May 1978 (after Levy et al., 1979).

Species	Scaled % recapture rate after		
	1 tidal cycle	2 days	7 days
Chinook	56.0	8.9	12.5
Chum	39.9	7.3	4.1
Pink	2.5	20.0	-

that harpacticoids were the predominant food in 11 out of 12 tidal channels (Table 23 - Levy and Northcote, 1981). Intersite differences in feeding were often only seen in the minor prey categories. It should be noted that occasional large switches in feeding did occur (the dominance of Daphnia as prey in the Ladner marsh sites, for example), apparently in response to local concentrations of an otherwise relatively rare prey.

Intertidal Flat Use

Juvenile chum were captured in very low numbers (1% of total salmon) on Roberts Bank by Goodman (1975) and only a very few observations of their trophic relationships are therefore available from the sandflat habitat. The prey of the 3 fish caught between Steveston Jetty and Canoe Pass consisted of fish (38.7% by biomass), estuarine invertebrates (gammarid amphipods and cumaceans) and plankton (the copepod Calanus glacialis). Between Canoe Pass and the Roberts Bank Causeway, 54.3% of their diet by biomass was fish and 38.2%, larval shrimp. Juvenile chum were only 0.1% of all fish caught in sector Canoe by Greer et al. (1980).

2.6.4 Coho Salmon Oncorhynchus kisutch (Walbaum 1792)

The coho is an important commercial species, accounting for 15.7% of the total B. C. commercial salmon landings between 1971-1980, with a total value[1] during that period of 205.2 million dollars. The commercial coho catch in the Fraser area averaged only 1.4% (range=0.5 - 2.5%) of the total B. C. catch between 1974 and 1980, with an average annual catch during that period of 157,000 fish, an apparent decline from the pre-1970's minimum of 500,000 annually (Northcote, 1974). Fraser coho stocks are the basis of an intensive sports fishery in coastal waters and river in summer and autumn as well as an Indian food fishery which averaged 85,000 lbs. annually in the 1960's (Northcote, 1974).

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[1] "value" here and elsewhere refers only to the total commercial landed value as given in the fisheries statistics.

Life History

Coho mature sexually and begin their spawning migration as three to four year olds and pass through the Fraser estuary as early as July (Northcote, 1974) but mostly between September and December (Goodman, 1975). The annual spawning escapement averaged 63,000 between 1957 and 1972. Spawning occurs mostly in October and November with fry emerging from the gravel the following April (Hart, 1973). For the first year of life, unlike the species discussed above, coho usually remain in freshwater streams where they defend feeding territories and prey mostly on insects (Hart, 1973).

Estuary Use

The seaward migration of coho smolts occurs in late spring and early summer (after the fish have spent approximately one year in freshwater) and is generally associated with the increased river flows during freshet (Northcote, 1974). The total number of smolts passing Mission averages 2.1 million annually (Goodman, 1975). Coho were captured in Woodward Island tidal channels in April (rare), May ("common" - 1 to 10 individuals per channel day sampling effort) and June (rare) although they evidently make little use of the marsh habitat (Levy et al., 1979).

Intertidal Flat Use

Coho smolts comprised 16% of the salmon captured on Roberts Bank by Goodman (1975). The diet of coho (from stomach analysis) varied with geographic location. The dominant prey of 117 coho smolts captured in the South arm of the river were chironomid larvae and salmon fry. Coho on Sturgeon and Roberts Banks (52 stomach examined) were mainly piscivores, with larval and juvenile herring and other fishes their main prey; however, those captured between Steveston Jetty and Canoe Pass had consumed the pelagic amphipod Parathemisto pacifica (47.1% biomass) and various estuarine benthic invertebrates - mostly cumacea (39.7%). Coho captured south of Canoe Pass and north of the Roberts Bank Causeway were piscivorous (85.9% fish, 12% larval benthos) (Goodman, 1975). Without long and detailed study of feeding and assessment of prey availability it is not possible to determine the causes of these large differences in prey composition to the north and south of Canoe Pass. The diet difference could be size-related since coho north of Canoe Pass ranged from about 45 to 145mm through the sample period (May to August) (Goodman, 1975 - Figure 26a) while those from south of Canoe Pass ranged from approximately 55 to 205mm during the same period (Goodman, 1975 - Figure 26b). Coho in both areas more than doubled in average length between mid-May and late August.

2.6.5 Chinook Oncorhynchus tshawytscha (Walbaum 1792)

The chinook is the most highly prized of the Pacific salmon for the fresh fish market (Hart, 1973). The Fraser is the most important system in B. C. for production of chinooks but through the period from 1953 - 1972 annual catches (87,500 - 180,000) showed evidence of decline (Northcote, 1974). Between 1974 and 1980 the Fraser area catches averaged 7.7% of the annual B. C. catch (range 3.9 - 10.3%). Fraser area catches through the period ranged from 39,000 (1980) to 99,000 (1977) indicating that the downard trend in chinook production may be continuing. Until late August over half the chinook catch consists of red fleshed fish; whites dominate until October, followed by Jacks (three year olds, mostly males) (Northcote, 1974). Chinooks support an annual sports fishery of about 1 million pounds in B. C. waters (Hart, 1973).

Life History

Most chinook salmon return to fresh water to spawn in their fourth or fifth year although spawning may be delayed until as late as eight years and some fish ("jacks") return as three year olds (Hart, 1973). Annual spawning escapements to the Fraser River averaged 51,000 (1957 - 1972) (Goodman, 1975). The timing of the spawning run varies among streams (Northcote, 1974). The earliest Fraser spawners (from the Lillooet River) begin their run in March/April (T. G. Northcote, pers. comm.). Most other major stocks return in August. The latest run (Harrison) occurs in November. Spawning streams are located from just beyond the limits of salt water penetration to 1000 km upstream (Hart, 1973). Fry emerge from early March until late May and although most begin the seaward migration as advanced fry, some may remain in fresh water for up to a year and migrate as smolts (almost all migrants from the Nicola River are smolts) (Northcote, 1974).

Estuary Use

Fry may be found off the mouth of the Fraser from April onwards. Growth is rapid during this period, with fry increasing from 4 - 5cm in April to 9cm in June to 13cm in July (Hart, 1973). The food of fry in the vicinity of the Fraser has been the subject of numerous studies. The dominant prey of chinook fry are small fish (sand lance, eulachon, herring, rockfish, smoothtongue) and insects but their diet also includes crustacea (amphipods, copepods, euphausiids, cladocera, crab larvae and barnacle larvae) (Hart, 1973).

An average of 16.8 million chinook fry migrate through the Fraser estuary each year (Goodman, 1975). Recent evidence (Dunford, 1975; Levy et al., 1979; Levy and Northcote, 1981) suggests that chinook fry spend an extended period (on the order of weeks to months) feeding within the Fraser marsh complex. The following discussion of estuarine marsh use is derived from Levy et al. (1979) unless otherwise noted.

In 1978, 43 million chinook fry migrated past Mission. The first fry were captured in the Woodward Island tidal channels on 21 March (Table B2 - Levy et al., 1979). Timing of peak densities (Figure 1) varied greatly among sites from 15 April (0.136 individuals/m^2) at "Stump TC", 7 May at Secondary TC (0.252/m^2) and 21 May at Main TC (0.120/m^2). No chinook were caught on Woodward Island after 6 July.

Like chum, chinook fry pause on their seaward migration for a time within the marsh system. From the large increase through time observed in the lengths of chinook caught in the marsh and a comparison of the size of fry at Mission with the fry in the marsh, Levy et al. (1979) concluded that chinook grow during the period of residence (from approximately 4cm in March to 7cm in June). Similar observations were reported by Dunford (1975). In addition, size differences among fish caught in different parts of the marsh were noted: in June larger fish were caught on Woodward Island compared with the foreshore; the situation was reversed in July.

Large numbers of juvenile chinooks were recovered in mark recapture experiments on Woodward Island (some up to one month after release) (Table 2.6-1). Chinook fry also exhibited a high fidelity for particular tidal channels.

Trophic Relationships

Chinook fry in the marshes exhibited a greater flexibility in feeding than chum fry (Levy and Northcote, 1981). The mean length of 51 fry included in the feeding analysis (caught between 28 March and 23 June 1978) was 49.2mm. Insect (especially chironomids) pupae were the dominant prey (65.5%), followed by insect adults and larvae (11.5%), the amphipods *Corophium spinicorne* (4.3%) and *Eogammarus confervicolus* (2.4%) and the mysid *Neomysis mercedis* (4.2%). Harpacticoid copepods which were 11% by volume of the diet of the smaller (mean length = 42.6mm) chum fry and 49.8% of the diet of the still smaller pinks (33.5mm) were only 0.02% of the diet of the chinooks. Chinooks switched feeding behavior apparently to respond to local concentrations of prey; for example, they consumed large quantities of the planktonic cladoceran, *Daphnia* in Ladner marsh. Similar observations of trophic relationships of chinook fry within the marshes were made by Dunford (1975).

Although there are no precise estimates of the total number of chinook which use the Fraser marshes as a rearing area, it is on the order of tens of millions annually (Levy and Northcote, 1981). This period of residency and growth is critical to the fish for three reasons (Levy and Northcote, 1981):

1. Adult survival is related to the size of juveniles leaving the estuary.

2. Larger chinook juveniles are more salinity tolerant.

3. Larger juveniles are less vulnerable to predation.

Sand Flat Use

Chinook fry were the most abundant juvenile salmon on Roberts Bank (82% of all salmon caught) in 1973-1974 (Goodman, 1975) and were also abundant in the South Arm of the Fraser. Chinook captured in the river (n = 529) had eaten mainly insect larvae, while those from the banks were mainly piscivorous. On Roberts Bank between Steveston Jetty and Canoe Pass, 78.7% (by biomass) of their diet was larval and juvenile herring and 14% mysids. South of Canoe Pass, 61.5% was fish, 18.0% mysids and 14.9% the pelagic crustacean, *Euphausia pacifica*.

2.6.6 Sockeye Salmon Oncorhynchus nerka (Walbaum 1792)

The Fraser River system is one of the world'a largest producers of sockeye salmon with a landed value exceeding 15 million dollars annually between 1952 and 1969 (based on 1970 prices) (Northcote, 1974). The sockeye is the most valuable of Canada's Pacific coast fisheries although, over the long term, production has declined, largely due to the obstruction of fresh water habitat by rock slides (Hart, 1973). Between 1974 and 1980 sockeye accounted for 24.3% of all B. C. salmon landings with a total value over the seven years of 259 million dollars. Catches in the Fraser area ranged from 292,00 (1980) to 1.18 million (1977) and contributed an average of 14.3% (from 7.7% in 1978 to 20.6% in 1979) to the B. C. total through this period.

Life History

Most sockeye spend one year in fresh water and two years at sea before returning to the spawning grounds; this produces a four year cyclic dominance in run size (the "1902" cycle) (Hart, 1973). Smaller numbers of fish spend three, four or one years in the ocean, producing sub-dominant run cycles (the 1901, 1903 and 1904 cycles). These complex cycles are discussed in greater detail in Northcote (1974) and will only be reviewed briefly here. The information is derived from Northcote unless otherwise noted. The annual escapement of sockeye to the Fraser averaged 1.25 million fish between 1957 and 1972 (Goodman, 1975). Mature fish approach the river beginning in late May; most enter through the main arm. The early spawning races (for example, the Stuart) immediately enter the river but subsequent arrivals delay at the river mouth for periods which increase as the season progresses. Fish which arrive in August delay for a few days and the Adams river fish, which arrive in September, for a period of two to six weeks. Large concentrations of fish coupled with strong northwest winds result in large catches in the Point Roberts area - called "blowback" or "driftback" by the local fishermen. Substantial catches in the Fraser begin in late June. Maximum catches are taken in late August - mid-September (1902 cycle) or mid-July - August for other cycles.

Sockeye make very long spawning runs to which their energy needs are finely tuned, therefore, delays on the upriver migration (for example, due to physical obstruction) may have disasterous consequences for the stocks (Hart, 1973). The timing of spawning varies considerably among races from early August to late November.

Most sockeye pass through a lake to spawn in its inlet stream. Eggs incubate for 50 days to five months (Hart, 1973) and the fry are carried into the nursery lake where most reside for one year before migrating to sea as smolts (6 to 9.5cm long). The average number of outmigrating smolts is 46 million per year (Goodman, 1975). While in the nursery lake the fry feed on insects and their larvae and crustacea (cladocera, copepods and amphipods) (Hart, 1973). Some sockeye (for example, Harrison fry) migrate to sea as fry in their first year (Northcote, 1974). The timing of smolt migrations is variable both among different stocks and between years. During the seaward migrations, smolts feed on benthic invertebrates.

Estuary Use

The available data suggest that, in general, sockeye juveniles do not delay in the Fraser estuary. Many (especially those which migrate as fry) seem to remain inshore in their first summer in salt water, feeding at the outlet of the Fraser river (Hart, 1973; Healey, 1978). Juveniles (4 to 13cm long) in the Fraser plume area feed mainly on insects, crustacea (copepods, amphipods, decapods, barnacle larvae, ostracods, euphausiids) and the young and larvae of a number of fish species (Hart, 1973). Healey (1978) studied the distribution and feeding of young salmon in the Strait of Georgia. With the exception of those which migrated as fry, he suggested that sockeye move quickly through the Strait. Large numbers of young fry were captured in the plume area between Point Grey and Howe Sound. Sockeye were generally present for only one to two months in spring although large concentrations were found in Howe Sound in September 1976. The diet of sockeye in the Strait consisted of amphipods (54%), crab larvae (15%), insects (10.9%) and fish (10.5%).

Sockeye juveniles appeared to move quickly through the Fraser marshes (Levy et al., 1979), although they were common in Woodward Island tidal channels between April and July. The gut contents of 23 fry (mean length = 54.3mm) captured on 18 - 19 July 1978 consisted of insect adults (28%), insect pupae (26.3%), insect larvae (13%), Neomysis mercedis (2.7%), Eogammarus confervicolus (0.41%) and harpacticoid copepods (0.3%).

Sand Flat Use

Sockeye were less than 1% of all salmon juveniles captured on Roberts Bank by Goodman (1975) although they comprised 7% of the salmon caught on Sturgeon Bank. Sockeye (between six and 10cm long) were found on Roberts Bank only between Steveston Jetty and Canoe Pass in June and early July. Their food consisted of larval benthos (63.5% by biomass), particularly crab zoea and megalopa, and fish (35.5%). Sockeye were fourth in abundance among the juvenile salmon caught in the South arm of the river, where their guts contained chironomid larvae, cladocera, Bosmina sp. and harpacticoid copepods.

2.6.7 Threespine Stickleback Gasterosteus aculeatus (Linnaeus 1758)

Of the nine other migratory species which occur in the Fraser (listed at the head of this section), only the threespine stickleback was caught in sector Canoe by Greer et al. (1980); it represented only 0.2% of all fish caught in the sector. The stickleback spawns in summer in fresh water; the young migrate to the estuary during their first summer where they are important prey for trout, salmon and birds (Northcote, 1974). Stickleback live for up to 3.5 years; following sexual maturity in their first year of life they migrate annually to spawn in fresh water streams (Beak, 1977).

Threespine stickleback were abundant (more than 10/channel - day sampling effort) in the Woodward Island tidal channels in all months except January and February 1978 (Levy et al., 1979). Between March and August 1978 the gut contents of 93 fish (mean length = 46.0mm) were analysed. Their dominant prey were insect larvae (31.7% by volume) and pupae (6.0%), and crustacea (Eogammarus confervicolus, 14.5%; Neomysis mercedis, 11.5%; harpacticoid copepods, 3.8%; Corophium spinicorne, 3.3%; and Gnorimosphaeroma oregonensis, 2.0%). The threespine stickleback was the fourth most abundant species in Roberts Bank catches by Goodman (1975).

2.6.8 Eulachon *Thaleicthys pacificus* (Richardson 1836)

The eulachon is an important member of the estuarine food web as well as a minor commercial species in the Fraser; it is also an important traditional food source of native Indians (Northcote, 1974). Largest catches were recorded between 1895 and 1904, and between 1941 and 1968 (Northcote, 1974 - Figure 4). Between 1974 and 1980 annual catches were relatively low, averaging 36.5 metric tonnes (from 22 in 1979 to 75.3 in 1974) with a total landed value ranging from $15,000 in 1980 to $37,000 in 1974.

Life History

Eulachon reach sexual maturity at the end of their third year (Hart, 1973). Spawning occurs in the Fraser River Mainstem (mainly between Mission City and Chilliwack) from mid-March to mid-May (Northcote, 1974), with the largest commercial catches taken in April. Larvae (about 5 to 7mm long) hatch after 30 to 40 days incubation and quickly drift into the Strait of Georgia or out to sea (Hart, 1973). Early feeding larvae eat mainly copepod nauplii; larvae and postlarvae between 2.5 and 5cm long eat phytoplankton, crustacea (copepods and their eggs, mysids, ostracods, barnacle larvae and cladocera), worm larvae, and larvae of their own species. Larger juveniles and larvae eat larger zooplankton: copepods and euphausiids (Hart, 1973).

Marsh/Estuary Use

Larval eulachon were captured in drift samples in Canoe Pass from January to July; maximum densities occurred in April to late June and numbers fell off sharply in July (Levings, 1980). Eulachon were common in the Woodward Island tidal channels in April and May (Levy et al., 1979) but did not appear to make use of the intertidal flats of Roberts Bank (Goodman, 1975; Greer et al., 1980).

2.6.9 Surf Smelt *Hypomesus pretiosus* (Girard 1855)

The surf smelt is an abundant species in brackish waters and supports a gill net and purse seine fishery in British Columbia of minor commercial importance.

Between 1974 and 1980 smelt landings in the Fraser area averaged three metric tonnes annually (0.45 in 1974 to 9.5 in 1976) with a landed value between $330 in 1974 and $5,700 in 1976.

Surf smelt spawn at high tides through most of the year on beaches protected from excessive surf action (Beak, 1977). Small (about 3mm long) larvae hatch after an incubation period which varies seasonally. Their subsequent biology is not well known, although they probably spawn repeatedly and may live for as long as three years (Hart, 1973).

Surf smelt were common from October to April in Woodward Island tidal channels (Levy et al., 1979); their trophic ecology in the marshes was not studied. Smelt were the seventh most abundant species on Roberts Bank (Goodman, 1975) but were not captured in the Canoe sector by Greet et al. (1980) although they comprised 2.9% overall of all fish caught on Roberts and Sturgeon Banks in that survey.

2.6.10 Longfin Smelt *Spirinchus thaleicthys* (Ayres 1860)

Longfin smelt were present in Woodward Island tidal channels in varying numbers through most of the year (Levy et al., 1979) although they are not common enough in the waters around the Fraser to support a commercial fishery (Northcote, 1974). Adults spawn in streams from October to December and there is some indication that the young may reside in the river or estuary for an extended period (Northcote, 1974). Fish up to 74mm long were caught near New Westminster; they had been feeding on *Neomysis* (Hart and McHugh, 1944, cited in Northcote, 1974). The stomach contents of 20 specimens averaging 86.5mm long (captured on 28 and 30 November 1978 on Woodward Island) consisted almost entirely of estuarine crustacea (80.6% *Eogammarus confervicolus*, 15.3% *Neomysis mercedis*, 1.3% *Corophium spinicorne* and 0.2% *Gnorimosphaeroma oregonensis*.

Other Migratory Species

Of the five remaining migratory species which occur in the Fraser, Coastal cutthroat trout and steelhead trout support important sport fisheries. The American shad is an introduced species which spawns in the Fraser and is occasionally taken commercially in southern coastal B. C. waters and in the Fraser River.

The biology of these three species as well as the two parasitic lamprey species were extensively reviewed by Northcote (1974). The summaries of the biology of cutthroat, steelhead and shad presented below are taken from this source.

2.6.11 Coastal Cutthroat Trout *Salmo clarki clarki* (Richardson 1836)

There is some evidence to suggest that this psecies has been on the decline in the Fraser system in recent decades. Adults spawn in small tributary streams of the Fraser from November to May; most young migrate to the estuary and coastal waters in the spring of their second or third years. Most juveniles apparently rear in the estuary where they prey heavily on small fish such as sandlance, salmon, rockfish, seaperch, flatfish and sculpins, and crustacea.

2.6.12 Steelhead Trout *Salmo gairdneri* Richardson 1836

The steelhead is the sea going form of the rainbow trout. The major part of the spawning run in the Fraser occurs from November to April ("winter steelhead") although a summer run of sexually immature fish (from the Coquihalla River) occurs in June to September. Steelhead may spawn up to three times before dying. The young emerge in summer but remain in fresh water for a year before migrating as smolts between April and June. Although juveniles may feed there temporarily it is likely that the estuary functions mainly as a passage channel for both juveniles and returning adults. Fraser steelhead stocks support commercial, sports and native Indian fisheries.

2.6.13 American Shad *Alosa sapidissima* (Wilson 1812)

The shad is a large, introduced species of the herring family. The Fraser appears to be at the northern limits of its spawning range. Spawning occurs in late spring, with the young rearing either in the estuary or near the river mouth. Small quantities are taken commercially.

Semi-Migratory Species

Of the six semi-migratory fish species in the Fraser listed by Northcote (1974 - Table 1), two species are abundant in the vicinity of the proposed pipeline route: Starry flounder and Staghorn sculpin. The biology of the other four species is reviewed in Northcote (1974).

2.6.14 Starry Flounder *Platichthys stellatus* (Pallas 1811)

The starry flounder is a marine species which is highly tolerant of low salinities and often occurs in the Fraser estuary and lower reaches of the river (Northcote, 1974). The starry flounder is fished in B. C., but is not highly regarded as a commercial species (Hart, 1973). The Fraser area generally contributes less than one metric ton to the annual B. C. commercial catch which ranged from 51 metric tons (1976) to 309 metric tons (1980) in the 1974 - 1980 period with a total landed value of $7,000 (1976)to $60,000 (1980).

Life History

The biology of the starry flounder was reviewed by Hart (1973) from which the following summary is taken. Flounder spawn each year in shallow water between February and April. Larvae (2mm long) are symmetrical and planktonic. Between 5 and 12mm they eat planktonic crustacea (copepods and their naulpii, barnacle larvae and Cladocera). At 10.5mm the fish become asymmetrical and begin to feed on the benthos. Their food consists of crabs, shrimps, worms, clams (and their siphons), other small molluscs, small fishes, nemertean worms and brittle stars.

Estuarine Marsh Use

Recent evidence suggests that the estuarine marshes of the Fraser may be important rearing habitat for the starry flounder (Levy et al., 1979). Juveniles were common in Woodward Island tidal channels in all months and abundant in November, June and July. Between 28 November 1977 and 19 July 1978, the diet of a sample of 85 fish (mean length = 134.6mm) consisted of insect larvae (39.3% by volume), *Gnorimosphaeroma oregonensis* (17.1%), *Corophium spinicorne* (9.4%), *Eogammarus confervicolus* (7.9%), insect pupae (6.8%), *Neomysis mercedis* (3.0%) and fish (2.6%).

Intertidal Flat Use

Starry flounder was the fifth most abundant species caught on Roberts Bank by Goodman (1975). In sector Canoe the starry flounder was the most abundant species captured in beach seining in 1979 (Greer et al., 1980), making up 55.8% of the total catch. Catch per unit effort (43.9 compared with 14.2) was three times higher at inner bank sites (stations 117 to 125) than at outer bank sites (stations 18 to 23). The highest single catch (100 individuals) was at site 125 on the northern margin of the Brunswick Point marsh. Sector Canoe appears to be a better than average habitat for flounder; 21.3% (480/2252) of the total catch from Roberts and Sturgeon Banks were from that sector although it received only 7.8% of the total fishing effort.

2.6.15 Pacific Staghorn Sculpin *Leptocottus armatus* Girard 1854

Staghorn sculpins are common residents of tidepools from northern California to the Gulf of Alaska (Hart, 1973). Although they are of no commercial importance, they are very abundant in parts of the Fraser estuary; they were the second most abundant species captured in sector Canoe by Greer et al. (1980) (= 35.2% of total catch per unit effort - CPUE - for that sector).

Estuarine Marsh Use

Staghorn sculpins spawn in February (Hart, 1973). Small juveniles (less than 50mm long) appear in the Fraser marshes from mid-April onwards (Levy et al., 1979). The following summary of what is known of their biology in the marshes is derived from Levy et al. (1979). Sculpins were present in all months but February and were abundant through the summer and fall of 1978. The feeding of two size classes was studied through this period: small individuals (less than 100mm long) which averaged 78.3mm (n = 50) and were collected between 28 March and 18 July and large individuals (greater than 100mm) which averaged 134.9mm (n = 109) and were collected between 12 October 1977 and 14 August 1978. The main prey of both size classes were relatively large epibenthic crustacea. The percent contribution (by volume) of prey groups was *Eogammarus confervicolus* 29%, *Neomysis mercedis* 21.5%, insects 10.7%, *Gnorimosphaeroma oregonensis* 8.2%, *Corophium spinicorne* 6.9% for small fish and *E. confervicolus* 24.6%, *N. mercedis*

24.0%, G. oregonensis 24.2%, fish 17.8%, C. spinicorne 2.4%, and insects 1.3% for large fish. Although juvenile salmonids were infrequent in sculpin diets, Levy et al. (1979) caution that any development in the estuary which would decrease the availability of the three preferred invertebrate prey species could cause a significant increase in sculpin predation on salmon fry.

Sand Flat Use

Overall, sculpins were the second most abundant species in sector Canoe (Greer et al., 1980). They were much more abundant on the inner flat (CPUE = 36.1) compared with the outer flat (CPUE = 0.5). It is especially notable that the largest catch was at site #121 which appears to be a large drainage channel (Greer et al., 1980 - Figure 2b). Reports on the trophic ecology of these fish on the banks are not yet available.

Harrison (1981) studied the diets of juvenile staghorn sculpins (13 to 47mm long, n = 40) in sand flat tide pools north of the Iona Island Sewage Jetty on Sturgeon Bank. The diets of the fish were highly variable among sampling dates; however, amphipods (Eogammarus confervicolus and Corophium sp.) were the most abundant prey (up to 36.7% by volume) followed by harpacticoid copepods (up to 32.7% of prey of smaller fish), mollusc siphons (to 19.1%), polychaetes (to 15.8%) and mysids (up to 13.5%).

Other Species

In addition to the 14 species discussed in some detail above, and the two lamprey species, 17 species (1 anadromous, 5 marine and 11 freshwater) were present during some parts of the year in the Woodward Island tidal channels (Table 1 in Levy et al., 1979). With the exception of Pacific herring (common to abundant in winter), prickly sculpin (common to abundant in summer) and peamouth chub (abundant in summer), these species were rare.

2.6.16 Pacific Herring Clupea harengus pallasi Valenciennes 1847

The Pacific herring is a valuable commercial species in B. C. Between 1974 and 1979 its total landed value increased from 12 million dollars per year to

124.4 million dollars; up to 97% of the herring catch through this period was for the Japanese roe market. In 1980 the total landed value of herring fell to 27 million dollars (a drop of 78% over 1979) due to price changes in foreign markets. The harvest of spawn from kelp added another 1.2 to 4.6 million dollars between 1977 and 1980.

Life History

The following brief summary of the life history and ecology of the Pacific herring is from Hart (1973). Fish mature between their second and fourth years. Spawning occurs in late winter (peaks in March) on beaches between the high tide mark and 11m depth. The eggs adhere to submerged vegetation (eelgrass, kelps and other seaweeds) and sometimes rocks and pilings. The eggs hatch in about ten days. The Strait of Georgia in the vicinity of the Fraser River plume is an important nursery area during summer, where the juveniles feed on a variety of zooplankton, mainly copepods. Movement to deeper waters occurs during the fall of the first year. Herring are important prey of chinook and coho salmon, waterfowl, sharks, lingcod, sealions and whales.

Marsh and Intertidal Flat Use

Herring occurred in the Fraser marshes during winter (Levy et al., 1979). They were not captured in sector Canoe by Greer et al. (1980) although they comprised 23.6% of all fish caught on Sturgeon and Roberts Banks in that survey. Highest seine catches were recorded in the Roberts Bank borrow pit (CPUE = 93.6), between the North Arm and Iona Island jetties on Sturgeon Bank (CPUE = 58.3), the "Sturgeon Pit" (CPUE = 57.8) and in the vicinity of the Ferry Terminal (CPUE = 23.8). High herring catches in the first two of these areas were previously recorded by Goodman (1975); their stomachs contained mainly planktonic crustacea and larval and juvenile fish.

2.6.17 Ecological Relationships

Although much remains to be learned regarding the role of the Fraser River estuary in the ecology of the fishes which pass through it on their migrations, use it as rearing and/or spawning grounds or spend their whole life in it, the data collected in the 1970's have largely confirmed early suppositions that the estuary is an important habitat for both commercial and non-commercial species.

2.6.18 Temporal Patterns

Migratory species pass through the estuary twice during their life history: first, as juveniles on their way to the sea (mainly in the spring months) and again, from one to several years later as adults on their way to the spawning grounds (mainly in the autumn months). The timings of these migrations are provided in the life history discussions of the various species. Figure 2.6-1 summarizes the timing of the major passages through the estuary by juveniles and adults of the commercially important species. The temporal pattern of marsh residence is shown in Table 1 of Levy et al. (1979).

From Figure 1 and Table 3 of Levy et al. (1979) it is evident that some fish will be found in the vicinity of the proposed pipeline route year round. Juveniles are present in the marsh and in Canoe pass itself in spring. The first salmon fry arrive as early as February in some years and although most have moved on by mid-June, juvenile chinook may be found in the marshes as late as 6 July (Levy et al., 1979). In recognition of the conflict between dredging activities and the survival of migrating fry, the Fisheries service prepared guidelines for the operation of dredges in the Fraser (Fisheries and Marine Service 1976, Technical Report Series No. PAC/T-75-2). The timing of peak fry migrations as given in the report are shown in Table 2.6-2. Dredging activities are to be suspended in the river mouth between 15 March and 31 May, although this period may be extended to include 1 March - 15 March or 1 June - 15 June in years of unusually early or late migrations. In view of the more recent findings of Levy et al. (1979) and Levy and Northcote (1981), it is particularly critical that no disruptive activities occur in the marshes during this period.

The migration of adults through the estuary occurs throughout the year, although maximum activity is between June and October (Figure 2.6-1). Considerable year to year variation in run strengths is noted and the patterns are very complex. The dominant variations are those caused by the two year pink cycles and the four year sockeye cycles. The timing of these cycles over the next six years is

Figure 2.6-1

Seasonal usage of lower mainstem Fraser River by the major species of migratory fish.

A - Northcote, 1974
B - Levy, et al., 1979
C - D.F.O. catch statistics for Canoe Pass Native Food Fishery, 1980

(for A′: total numbers found in lower mainstem Fraser River - 10^3 to 10^8 ▬
- $< 10^3$ ╍)

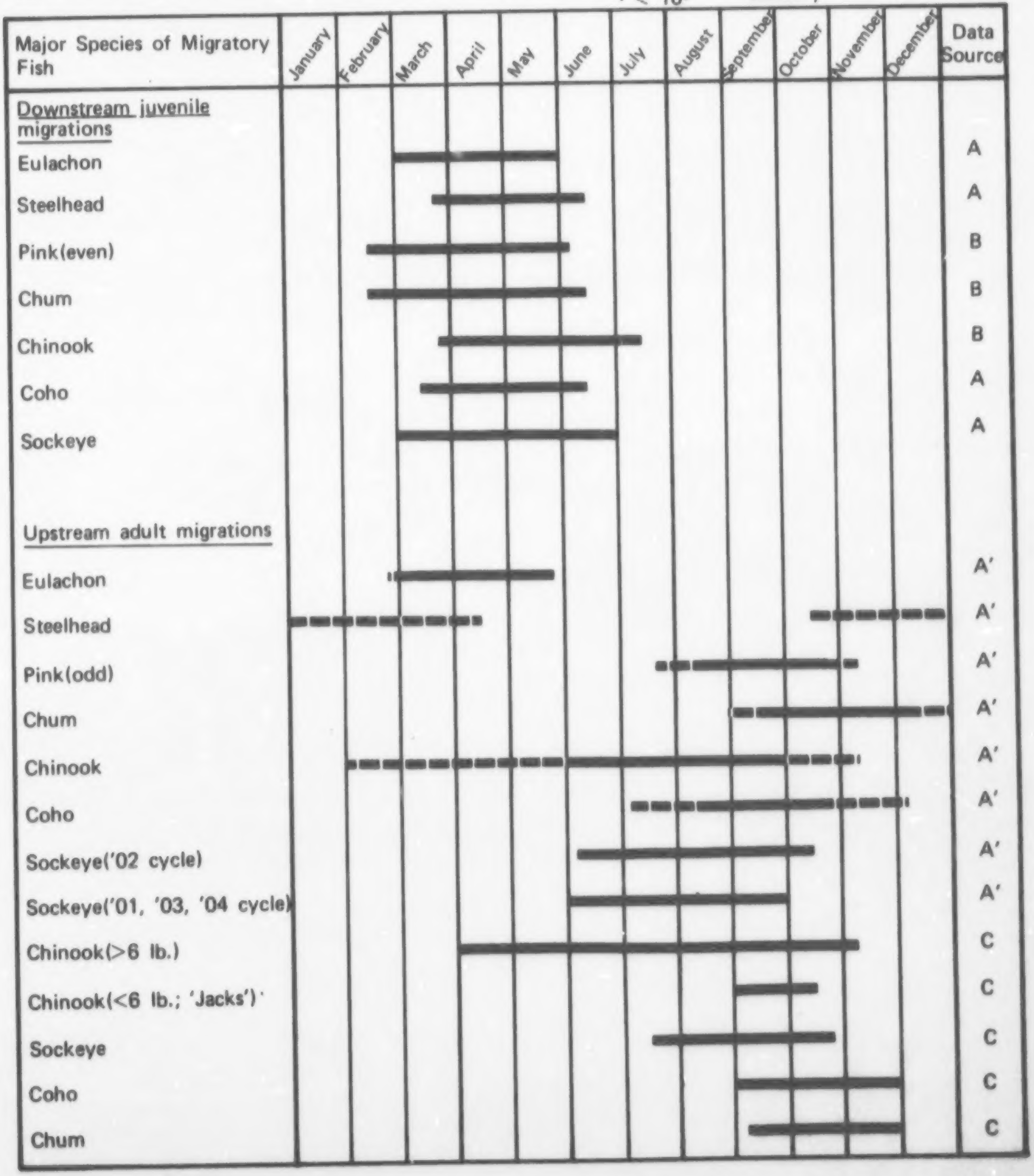


Table 2.6-2 Timing of peak migrations of major commercial fish species in the lower Fraser River (from: Anon. 1976).

Species	Adult Migration & Spawning	Incubation & Fry Rearing	Fry Migration
Sockeye	July - October	October - June	March 15 - June 30
Pink *	September - November	November - May	March 15 - May 31
Chum	October - January	January - May	March 15 - May 31
Coho	September - December	December - May	March 15 - May 31
Chinook	August - December	December - May	March 15 - May 31
Eulachon	April 15 - May 20	May - July	June 15 - July 30

* Adults in odd numbered years; juveniles in even numbered years.

shown in Table 2.6-3. The largest sockeye run, the Adams (1902 cycle) occurs in the "non-pink" years of 1982 and 1986. In 1982, 1984 and 1986 large numbers of pink fry will migrate through the marshes.

Variations between years are noted in the timing of both juvenile outmigrations and adult spawning runs. Many of the fry migrations are associated with periods of increased river flows during freshet, the timing and strength of which varies from year to year depending on the rate and timing of spring melting of the drainage basin snowpack. Variations in timing between 1978 and 1979 were discussed by Levy and Northcote (1981). Larger numbers of chum and chinook fry occurred in the marshes in 1979 and the chinook fry persisted in the habitat longer in 1979 than in 1978. The authors suggested that fewer fry may access the marsh during years of high river flows and also remain there for shorter periods of time before being washed out.

Timing of adult spawning migrations into the Fraser area may be derived from fisheries statistics (monthly catch summaries); however, these are not specific to the Canoe Pass area. There is a native Indian fishery in Canoe Pass which has been closely monitored for the past two years. The following information on this fishery was provided to Mr. R. Kistritz in a meeting with Mr. John Lewis, Regional Fisheries Officer in Steveston (2 July 1981). Members of the Musqueum Band (5 to 20 boats) and a few members of the Tsawassen Band (2 to 4 boats) fish the area eastward of the mouth of Canoe Pass (between Brunswick Point cannery across to triangle on Westham Island) and up Canoe Pass, and Ladner and Woodward reaches. Between March and 1 July openings are for 12 hours, 1 day per week. From 1 July to October openings are 36 consecutive hours/week. Variations in catch per unit effort (CPUE) through 1980 are shown in Figure 2.6-2 (summarized on Figure 2.6-1).

Although fish catches are highly dependent on factors other than fish abundance, and are certainly not an unbiased sample, they do provide some indication of the approximate period of salmon migrations through Canoe Pass.

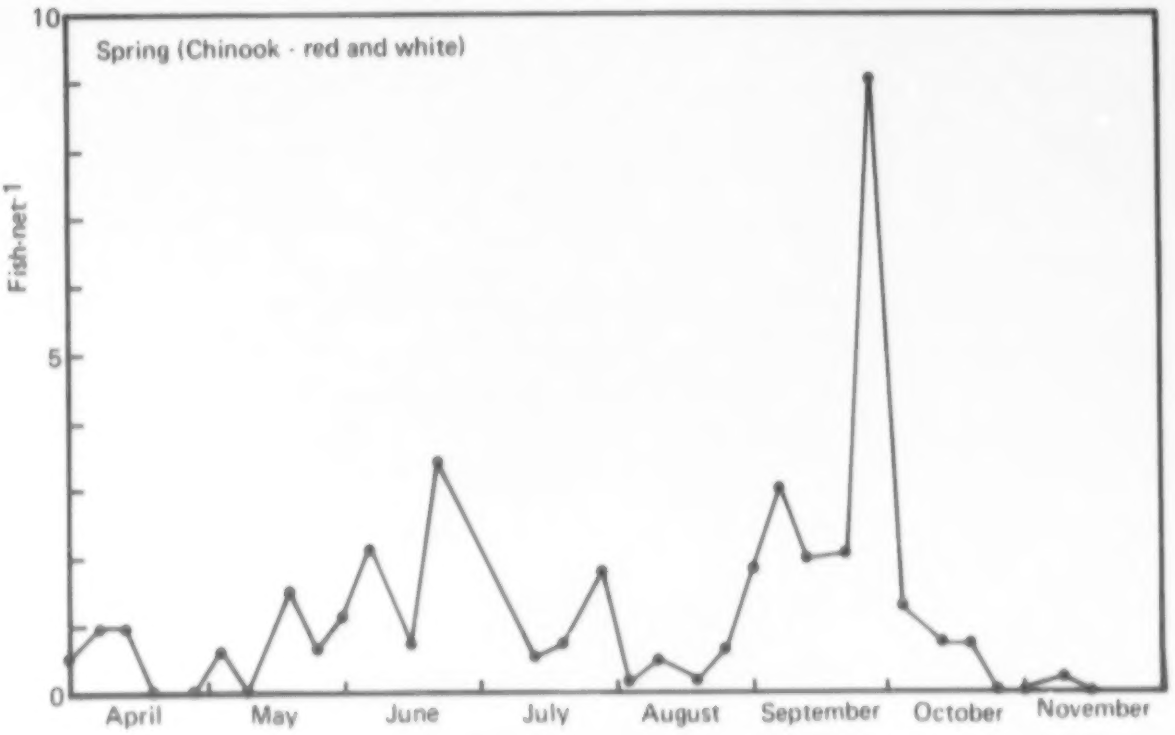
Table 2.6-3 Timing of expected large salmon spawning runs in the Fraser River. Summarized from Goodman (1975).

Year	Pink	Dominant Sockey Run		
		Adams	Chilco	Stuart/Quesnel
1980			X	
1981	X			X
1982		X		
1983	X			
1984			X	
1985	X			X
1986		X		
1987	X			

Adams - 1970-74 cycle
Chilco - 1968-72 cycle
Stuart/Quesnel - 1969-73 cycle

Figure 2.6–2

Catch per unit effort of salmon for 1980 Indian Food Fishery in Canoe Pass (from unpubl. statistics D.F.O.).



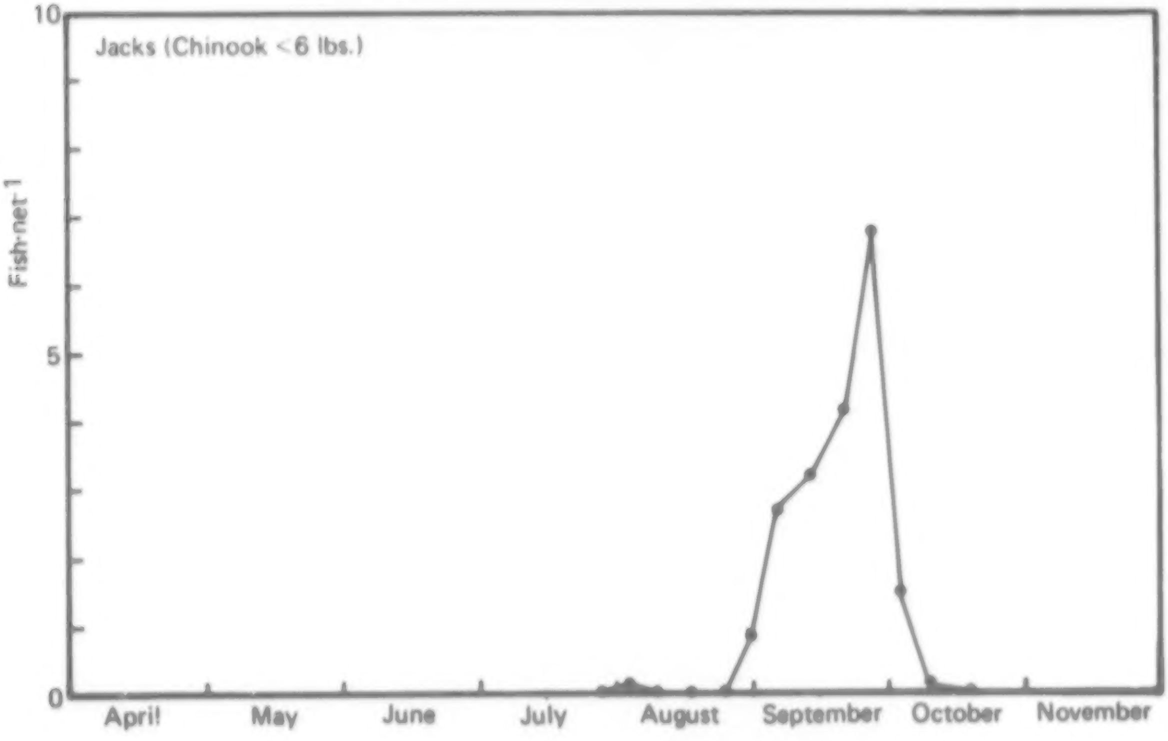
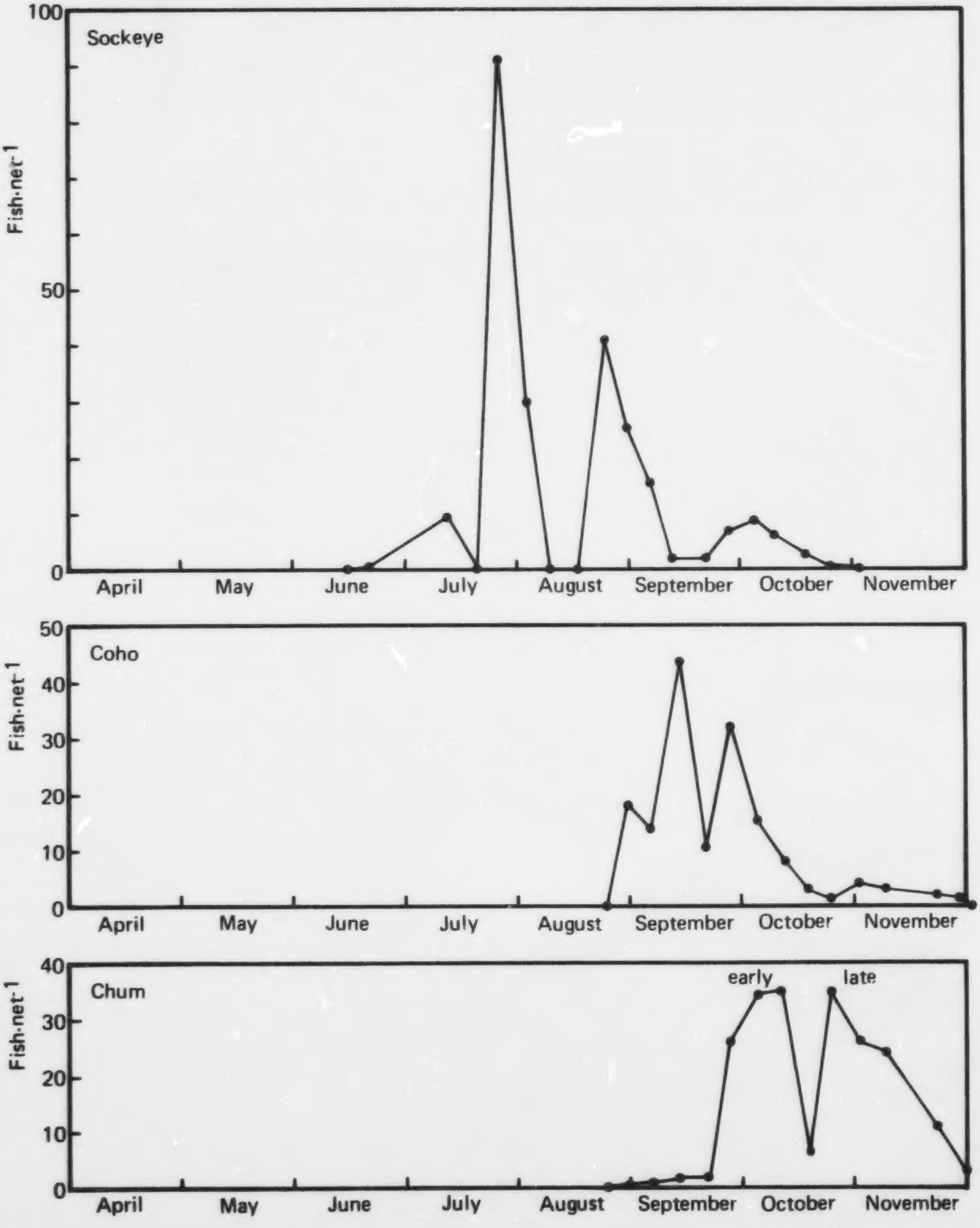


Figure 2.6-2(cont.)

Indian Food Fishery, Canoe Pass, 1980



2.6.19 Spatial Patterns

Spatial patterns of fish use of the estuary are not as well documented as temporal patterns, largely because of the logistic problems of sampling such a large and diverse system as the Fraser estuary. Several generalizations can be drawn from the existing data base regarding spatial patterns of fish distributions across the estuary as well as the use of various types of habitats within the area of the prosed pipeline route.

1. Sector Canoe Compared With Other Parts of the Banks

Total CPUE's by sector (from the seine survey of Greer et al., 1980) are summarized in Figure 2.6-3; the average CPUE for all species across Roberts and Sturgeon Banks was 89.2 individuals. CPUE for sector Canoe (58.3) was 65% of the average CPUE; 24.7% of the maximum (236.3 in the Borrow Pit on Robert's Bank). Further, only 5.2% of the total CPUE in Canoe were the commercially important salmonids (chinook, sockeye and chum) while 55.8% were Starry flounder which have a very low commercial value (Table 2.6-4). In general, the sand flats in the area of the proposed pipeline route seem to be of relatively minor importance as fish habitat, assuming that abundance of fish in the habitat reflects its "importance", especially when compared with such other areas as the intercauseway area on northern Sturgeon, Sturgeon Bank off the Middle Arm, sector STRPIT, and Roberts Bank south of the coalport causeway (Figure 2.6-3). The catches in sectors STRPIT and BORPIT are especially noteworthy and will be discussed in detail below.

2. Habitats Along the Pipeline Route

Of the four major habitat types along the proposed pipeline route (marsh/mudflat, riverine, sandflat, slope), the marsh/mudflat is extremely important as rearing area for juvenile fish (Levy et al., 1979). Levy and Northcote (1981) discuss the great spatial heterogeneity in fry utilization of the marshes. Not all marsh habitat is equally favourable; in general, good chinook rearing areas are marshes of low elevation. Also, chinook fry tended to reside longer on Woodward Island than on either the Ladner Marsh or Westham Island foreshore sites. Both the 1981 report and the report of Levy et al. (1979) emphasize the importance of

Figure 2.6–3

Summary of seine catches across Roberts and Sturgeon Banks (derived from Greer, et al., 1980; after Table XIII).

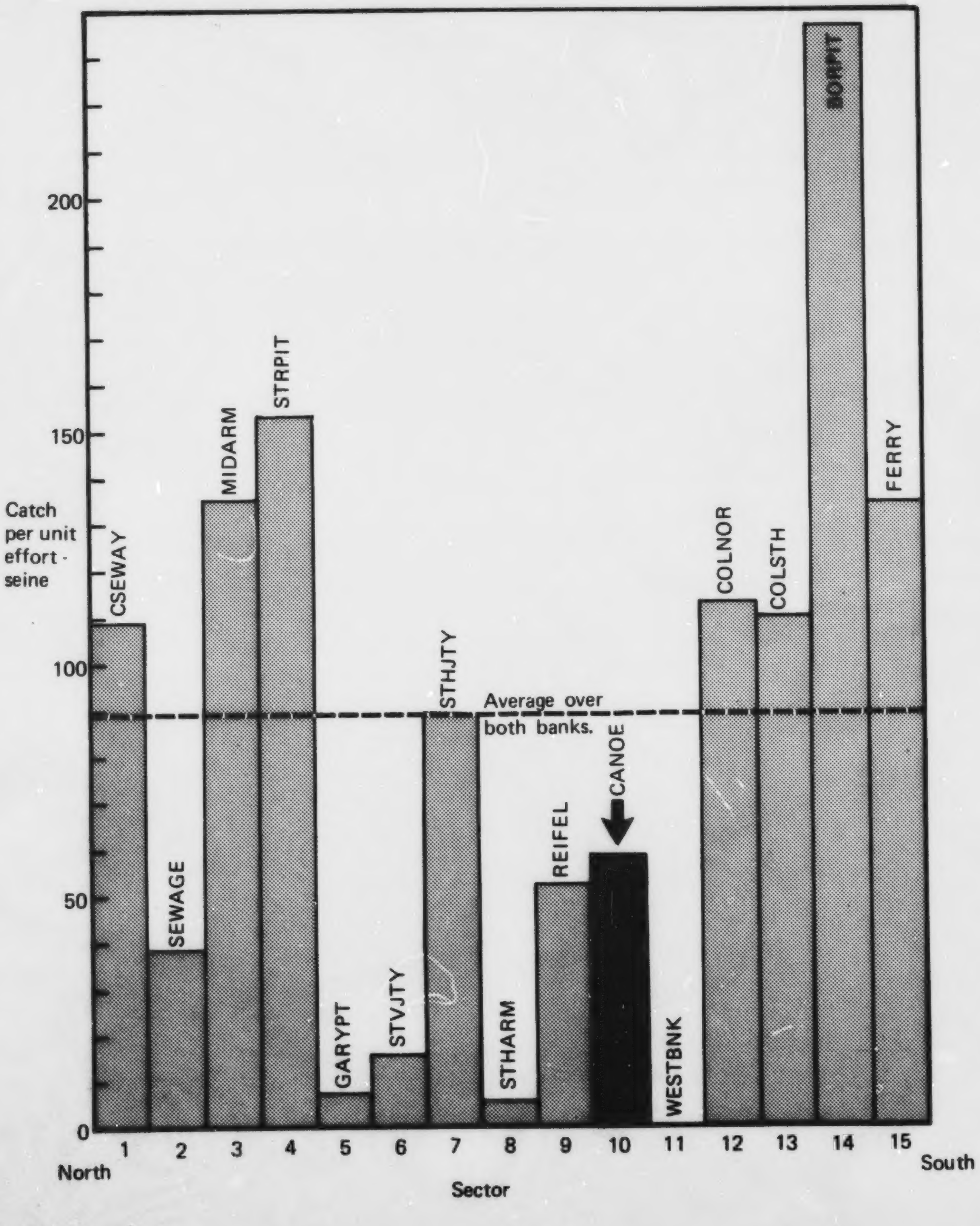


Table 2.6-4 Summary of fish catches in sector Canoe - calculated from Greer et al. (1980).

	Inner*			Outer**			Total	
	C	C/E	%	C	C/E	%	C/E	%
Starry Flounder	395	43.9	52.7	85	14.2	68.0	58.1	55.8
Staghorn Sculpin	325	36.1	43.3	3	0.5	2.4	36.6	35.2
Chinook	2	0.2	0.3	30	5.0	24.0	5.2	5.0
Peamouth Chub	17	[illegible]9	2.3	0	0	0	1.9	1.8
Sucker	6	[illegible]	0.8	0	0	0	0.7	0.7
Prickleback	0	0	0	4	0.7	3.2	0.7	0.7
Stickleback	2	0.2	0.3	0	0	0	0.2	0.2
Sockeye	2	0.2	0.3	0	0	0	0.2	0.2
Chum	0	0	0	1	0.2	0.8	0.2	0.2
Sandsole	0	0	0	1	0.2	0.8	0.2	0.2
Sculpin	1	0.1	0.1	0	0	0	0.1	0.1
Sandlance	0	0	0	1	0.2	0.8	0.2	0.2

* stations 117 - 125
** stations 18 - 23

tidal channel habitat in particular for the fry. The critical role of the Fraser marshes in the survival of salmonid fry, particularly chinook, chum, and pink hypothesized by Dorcey et al. (1978) has been confirmed by these recent studies. The marsh system is also important nursery habitat for a variety of other species.

Although migrating fish undoubtedly feed there, fast currents in the riverine habitat make it mainly a temporary habitat for the fish species considered in this report. During spring Canoe Pass provides access to the marshes and subsequently to the sea for many fry and smolts of anadromous species (particularly the salmonids). In addition, large numbers of eulachon larvae occur in spring in the Canoe Pass plankton. In late summer and fall, Canoe Pass provides access to the spawning grounds further up the river. For many species, particularly sockeye, which have limited energy reserves on which the spawning migration must be made, it is especially critical that the Pass not be obstructed during the spawning runs.

Fish use of the sandflat habitat has been discussed above. In the vicinity of Canoe Pass, the fish species which were most abundant on the sandflats were starry flounder and staghorn sculpin. Catches were much higher at inner flat sites than at outer ones (Table 2.6-4). The large drainage channel on the flat appears to be a major feature which attracts fish - largest catches of sculpins in Canoe occurred at station #121 near its mouth. Topographic depressions which retain water at low tide, whether natural or man-made, are refugia for the fish which use the flats. Consequently, large catches tend to occur in these areas. This was graphically illustrated in the seine results of Greer et al. (1980). Their largest catches were from the Roberts Bank "borrow pit" - a man-made depression created by dredging for the coalport facility -and two natural depressions - the Sturgeon Pit and the tidal channel network off the Middle Arm. In a recent, unpublished experiment, 900 juvenile chinook were marked and released into the Sturgeon Pit. Several marked individuals were recaptured on the following tidal cycle, indicating that juveniles may reside for several hours or more in such depressions on the flats (Dr. C. Levings, Dept. of Fisheries and Oceans, personal communication, 11 June 1981).

2.6.20 Trophic Interrelationships

The trophic relationships of the major juvenile fish species in the Woodward Island tidal channels (i.e. marsh habitat) are summarized in Figure 18 of Levy et al. (1979). Although each species has a unique diet, several general patterns are evident. First, the insect food chain is the dominant one for chinook, sockeye and chum fry, small staghorn sculpins and starry flounders. Next in importance are the epibenthic crustacea (= macrobenthos): *Eogammarus* (= *Anisogammarus*) *confervicolus* was the most important or second most important prey of four of the 11 species, the isopod, *Gnorimosphaeroma oregonensis* and the mysid *Neomysis mercedis* were the first or second prey in the diets of three species, each. Meiobenthic harpacticoid copepods were the most important prey of pink fry and the second most important prey of chum fry (compared with the Nanaimo estuary where production of chum fry appeared to be closely linked with production of harpacticoid copepods -Sibert, 1979). Chum fry in the Fraser appear to be more reliant on the insect food chain.

A far less comprehensive data base exists for the fish on the tidal flats. From the observations of gut contents that have been made, it is apparent that by the time salmonid juveniles are on the flats their food has shifted to include a much larger proportion of larval and juvenile fish; fish were the most important prey of coho smolts and chinook fry captured on the flats and secondary prey of juvenile chum and sockeye. Benthic and epibenthic crustacea and their juvenile stages (particularly gammarid amphipods, cumaceans, and juvenile crabs and shrimp) remained important in the diets of salmonids on the flats (particularly chum and sockeye). A variety of pelagic crustacea (amphipods, copepods, euphausiids and isopods) play an increased role in the diets of fish on the flats. The most abundant fish on the flat in sector Canoe, Starry flounder, is a truly benthic feeder - consuming crabs, shrimps, worms, molluscs and nemerteans.

3.0 IMPACT ASSESSMENT

3.1 Introduction

The anticipated environmental effects of the pipeline project discussed in this section are based on some of the common concerns expressed in the scientific dredging literature pertaining to environmental effects of dredging and open water disposal of dredged material. The typical environmental concerns evident in the literature were assessed in terms of their relevance to the technical details and expected physical effects of this project (Monenco, 1981) as well as in relations to the existing environmental conditions described in section 2.0 of this report.

A preliminary search for case history information about environmental effects of the bathtub method proved unsuccessful. Technical details concerning the construction of three gas pipelines since 1974 across the Eems estuary in Holland appears to be the only information directly relevant to this project. In 1975 a 9 km long crossing was made of intertidal sand-silt flats in the Eems estuary using the bathtub method. Unfortunately, no special reports about environmental considerations were produced.

For more general considerations of environmental effects of dredging the most comprehensive source of information is available in resuts of the more than 250 scientific studies commissioned by the U. S. Corps of Engineers, Dredged Material Research Program (DMRP, 1980). Discussions with scientific personnel of the DMRP in Vicksburg, Mississippi, on various potential environmental problems related to this project provided an improved perspective for making judgements about the degree of various potential impacts. Further insights were gained on the general nature of marine pipeline construction by visiting an hydraulic dredger and laybarge operation for a gas pipeline across the outer Mississippi delta. Numerous environmental topics are also compiled annually in Proceedings of the World Dredging Conference (e.g. WODCON VII, 1976).

Information on environmental effects of dredging in the Fraser estuary are limited to five key sources (Table 3.1-1) which are included in discussions of this section of the report.

Table 3.1-1 Published information sources pertaining to environmental effects of dredging activities in the lower Fraser River and estuary.

	Type of Dredging Activity	Information	Reference
1.	Airport Expansion hydraulic dredging and dredged material containment	predicting changes in water quality	Morrison et al., 1975 Pollutech, 1974
2.	Power Cable Trenching hydraulic jetting, mechanical backhoe to bury electric cable	measured changes of benthic organisms	Levings et al., 1978 B. C. Research, 1976
3.	Harbour Construction hydraulic dredging and aquatic disposal of dredged material	(i) measured changes in water quality (ii) predicted environmental effects	B. C. Research, 1976 Dobrocky, 1980
4.	Harbour Construction hydraulic dredging and aquatic disposal of dredged material	measured changes in water quality	B. C. Research, 1977(b) B. C. Research, 1976(d)
5.	Channel Dredging hydraulic suction dredge and aquatic disposal of dredged material	measured salmon fry entrainment	Dutta and Sookachoff, 1975

Environmental studies are currently being conducted by the NHB, Port of Vancouver in conjunction with dredging activities for expansion of bulk loading facilities at Roberts Bank superport. Field studies are planned throughout the two phased dredging operation (1981 to 1983) to monitor biological effects, investigate mitigation procedures, and develop habitat compensation techniques.

According to G. Ennis (pers. comm., D.F.O.) crab abundance will be monitored between -3 and -20 metre depths and plankton tows are to be conducted to sample larval crabs. The dredge material discharge will be monitored to determine crab and fish mortality.

Some proposed mitigation procedures may involve the use of underwater high frequency sound or bright lights to frighten crabs away from the dredging operation or intensive crab fishing in the general area to be dredged in order to deplete resident populations.

Compensation measures are to focus on replacing eelgrass areas lost by dredging and construction of artifical reefs to provide new habitat for fish.

3.2 Water Quality

The following assessment of the effects of dredging on water quality in proximity to the dredge and backfill operation is based on the existing geochemical and water quality conditions along the pipeline route (section 2.0) as well as on the proposed construction methodology detailed by Monenco (1981). Also, a general review of the literature concerned with environmental effects of dredging on water quality proved useful in identifying the environmental issues characteristic of dredging impacts in coastal ecosystems.

Effects of the pipeline construction on water quality conditions of Roberts Bank fall into the general category of environmental effects of hydraulic dredging and aquatic disposal of dredged material. However, several technical aspects of the dredging operation proposed for the B. C. Hydro gas pipeline project set it apart from many of the dredging operations described in the literature; namely:

1. Dredged material is deposited within 500 to 800m of its original location.

2. During most of the dredging operation, discharge of dredged material occurs within a flotation channel or so called "bathtub" (for further details refer to Monenco, 1981).

The existing sediment water conditions of Roberts Bank will also influence the water quality impacts of dredging along the pipeline route. Background information described in sections 2.2 and 2.3 characterize an estuarine environment with the following conditions:

1. Tides and currents are such that prevailing water masses are relatively well mixed.

2. Natural suspended sediment loads are generally high especially during the river freshet period.

3. Sediments are generally comprised of fine sand or silty sand with a mean particle size of approximately 0.2mm and a low percentage of clay (< 3%) and C.O.D. (< 2.7%).

4. Sediments along the pipeline route to not appear to be contaminated with toxic pollutants from anthropogenic sources.

5. The shallow water overlying the intertidal flats can be characterized as being well oxygenated, moderately buffered, of low to moderate productivity (nutrients) and with widely fluctuating salinity and temperature.

6. There are no existing water pollution problems in the immediate area of the pipeline route.

The construction details and environmental conditions described above are deemed to be some of the key factors influencing the effects of the proposed dredging on water quality and are used to set the stage for the following discussion detailing various specific water quality impacts.

3.2.1 Increased Turbidity and Suspended Sediment Levels

One of the most conspicuous water quality changes associated with the aquatic discharge of dredged material is the turbidity plume transported from the discharge point by prevailing tides and currents. Attempts at predicting or modelling plume characteristics are made difficult by numerous interacting physico-chemical processes characteristic of the estuarine environment. Since coarse grained suspended particles settle relatively rapidly, it is the silt and clay fractions (diameter < 0.03mm) which remain in suspension and are therefore of some concern.

Simple physical parameters such as discharge rate and settling velocity of dredged material, water depth and average current velocity, and duration of tidal excursions can be used to predict a "worst case" situation.

This type of rough approximation was made by Monenco (1981) to predict a "worst case" plume configuration and suspended solids concentration as a function of distance from the point of discharge. A suspended solids concentration of 400 g l^{-1} at the discharge nozzle would diminish to average river freshet levels (150 mg l^{-1}) at a distance of 1 km and to average river base flow levels (25 mg l^{-1}) at a distance of 1.7 km from the point of discharge.

Tidal currents would tend to disperse suspended solids along the direction of the pipeline route; outside and away from the "bathtub" on ebb flows and into the bathtub during flood tides. Cross directional currents associated with late flood gyres typical of the area (WCHL, 1980) would tend to transport the plume in a northerly direction near the foreslope and southeasterly further inshore.

Because of the generally brackish conditions existing at Roberts Bank, suspended silt and clay particles would rapidly flocculate thereby increasing the overall settling rate as these fine particles begin to coagulate. The effect of salinity on settling rates of Fraser River sediment (96.8% coarse sand, 2.4% fine sand, 0.8% silt), which is close in composition to the sediment conditions encountered along the pipeline route, was experimentally determined by Pollutech (1974). Results of settling tests showed an exponential decline in turbidity values where salinity was increased from 0 to 1 ppt. During the first four hours of measurement, turbidity values under 1 ppt. salinity diminished to approximately ¼ of the levels measured under freshwater conditions. It is during about a four hour period at high tide that the maximum effects of a discharge plume would occur in the proposed pipeline dredging.

Since sediments along the foreslope and in Brunswick marsh contain a greater proportion of silt and clay, overall turbidity and suspended sediments may be more evident in the discharge plume in those locations compared to the majority of dredging across the sand flats. Flocculation of suspended silt and clay and dissipation of the discharge plume may be reduced somewhat in Canoe Pass area particularly if freshwater entrainment occurs.

Environmental monitoring of discharge plumes from hydraulic dredging operations was commissioned by Public Works Canada for two locations in the lower Fraser River. In the North Arm (Point Grey scow mooring basin) ca. 350 x 10^3 cu. yds. of sediment composed primarily of silt and clay (83%) was dredged with a 26 inch pipeline dredge and discharged onto adjacent tidal flats (Mr. H. Wu, pers. comm.). Measurements by B. C. Research (1977 b) showed that suspended solids levels in the plume had reached background levels beyond 1000m of the discharge point at both downstream (ebb tide) and upstream (flood tide) locations. The data suggest that during flood tide most of the discharged material is confined to deeper layers (5 to 8m) whereas during ebb tide fine materials were more likely to reach the water surface. Similar observations were made during monitoring of disposal of Cannery Channel dredge spoils (B. C. Research, 1976 c). Dredged material was pumped into the Main Arm of the Fraser River via three submerged outfall diffusers approximately 8m below the water surface. Suspended solids concentrations in the discharge plumes were greater in surface water on the ebb compared to the flood tide. The highest levels were measured in deeper water (6.0m) suggesting rapid settling of much of the dredged material. Suspended solids in the plume did not reach background levels until some 6.8 km away from the dredged material outfall because of the high percentage of fine particulate matter (< 63μm) which made up about 85% of the dredged material (B. C. Research, 1976 c).

3.2.2 Dissolved Oxygen Reduction

Dredged material will impose an oxygen demand on water in the immediate vicinity of the discharge point as organic compounds and easily oxidizable reduced inorganic compounds become oxidized. Based on the physical and chemical characteristics of the sediment to be dredged, it can generally be predicted whether any high oxygen demand will occur during dredging. According to the particle size distribution, % C.O.D. and % volatile material in the sediments sampled along the pipeline route (Tables 2.2-3, 2.2-4) there is no evidence suggesting that dissolved oxygen reduction will be a major problem except perhaps in the immediate vicinity of the discharge nozzle. Existing dissolved oxygen concentrations in unpolluted sites of the Fraser estuary are high, generally exceeding 80% saturation (Drinnan and Clark, 1980).

Plume water downstream of dredging operations in the Fraser estuary generally showed no effects on dissolved O_2 levels with the exception of locations sampled within 100 feet of the discharge point where oxygen levels were depressed by 0.6 to 1.6 mg l^{-1} (B. C. Research 1976 c, 1977 b).

The above mentioned conclusions regarding anticipated oxygen reduction apply to a situation when tides are above local bank level and there is sufficient circulation and mixing to replenish any oxygen deficit. It is, however, worth examining a possible "worst case" situation during the short time that the "bathtub" is completely isolated when tides are at or below mean low tide.

Prior to entering Canoe Pass, the bathtub will be in a location where the maximum period of isolation during spring tides is three hours per day. The average volume of water isolated in the bathtub would be 1.75×10^8 1. A total of approximately 6.7×10^6 kg of dredged material would have been discharged into the isolated bathtub during the three hour period at an average rate of 619 kg sec^{-1}. The dredged material would begin to consume ambient oxygen as it comes into contact with water pumped into the dredger and during the period that it is discharged and settling into the isolated water mass of the bathtub. Oxygen uptake rates of Fraser River sediments with similar characteristics to those encountered along the pipeline route generally do not exceed 0.05 mg O_2 g^{-1} (dry wt. sediment) per 24 hours (B. C. Research 1977 a)*. Assuming that this 24 hour uptake rate is equal to an immediate oxygen uptake rate experienced over the first few hours of contact with the dredged sediment, then the total amount of sediment dredged during the bathtub isolation period would have the potential of consuming up to 3.35×10^8 mg O_2 or 1.9 mg 1^{-1} when expressed in terms of the total water volume present in the bathtub.

It is assumed that the isolated water mass would be relatively well mixed because of the shallow and exposed nature of the bathtub and since the dredging operation itself would be circulating approximately seven million litres of water per hour. Therefore, even under the "worst case" situation described above, dissolved oxygen levels should not reach levels below approximately 6.0 mg/l in the isolated water mass. Under these conditions any toxic reduced compounds would be readily oxidized thus preventing any accumulation of toxic contaminants such as those discussed in the following sections. According to the limnological literature (Wetzel, 1975) little change in redox potential occurs as long as the water contains some dissolved O_2. Only as the O_2 concentrations approach zero and anoxic conditions appear, does the redox potential decline rapidly.

Although it is probably valid to assume that the water mass in the bathtub will be relatively well mixed, an oxygen gradient may nevertheless become established near the sediment water interface. Since much of the discharged sediment slurry flows to the bottom of the bathtub even during high tide, a thin bottom layer of cxygen depleted sediment associated water may become established.

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* Percent volatile organic content ranged from 0.9 to 1.85 and percent dry weight of fine sediment fractions (< 63μ) ranged between 0.48 and 7.39.

3.2.3 Release of Toxic Contaminants

A common environmental concern expressed in the dredging literature pertains to the potential release of substances from dredged material at concentrations which may have lethal or sub-lethal effects on aquatic organisms or which may be taken up and accumulated in the food chain. Organohalogens and certain trace metals are contaminants known to adversely interact with the aquatic food chain whereas lethal and sub-lethal effects are commonly attributed to ammonia (NH_3) and hydrogen sulphide (H_2S). The release of large amounts of nutrients is identified as a problem mainly in terms of the aesthetically undesireable effects of eutrophication.

3.2.4 Organohalogens

Of the 14 stations sampled along the entire length of the pipeline route for organohologens (Table 2.2-5) not one sample contained any detectable levels of the pesticide DDT or its derivatives. Pentachlorophenol (PCP) was measured in some of the sediment samples because of some of the upstream sources of PCP pollution associated with effluents from wood preserving industries. The measured concentrations in sediment were well below those found in what are generally considered as contaminated sediment in polluted locations of the Fraser estuary. Levels of polychlorinated biphenyls (PCB) in sediments sampled along the pipeline route were generally below detectable levels or fluctuated within an expected range of values reported in the literature for various locations in the estuary away from pollution sources (Garrett, 1980).

Chlorinated hydrocarbons should not be released to solution in detectable quantities during dredging activities. However, there is some conclusive evidence that they exist in particulate phase especially in affinity with fine sediment fractions and macro-molecular organic compounds (Chen et al., 1976). The main concern is therefore with the uptake of chlorinated hydrocarbons by filter feeding organisms or deposit feeding detritivores.

Because of the relatively short duration that dredged material will be in suspension, the low percentage of fine particulate matter and the low or non-detectable levels of organohalogens present in sediments along the pipeline route, toxic organic contaminants are not considered likely to become a problem for the proposed pipeline project.

3.2.5 Trace Metals

Samples taken along the pipeline route were tested for eight different metals to determine if any particularly high concentrations are evident at certain locations or depths. Federal government guidelines are set specifically for mercury and cadmium in the solid phase of waste under the Ocean Dumping Control Act of 1975. Results of sediment analyses discussed in section 2.2.2.4 of this report show that both mercury and cadmium levels generally range below the 0.75 ppm and 0.6 ppm limit prescribed under the ODCA. Furthermore, all of the other measured trace metal values reflected the general pattern of concentrations expected for natural unpolluted sediments in the Fraser estuary.

It is recognized that bulk chemical analyses of sediment trace metal contents provide only a preliminary and inconclusive assessment of the actual mobility of various geochemical fractions. However, in the absence of sites along the pipeline route with known contamination, any further detailed chemical analyses are not considered necessary.

If chemical contaminants are suspected to be associated with hydraulically dredged sediments disposed of in open water, a standard elutriate test is often employed. This test basically attempts to simulate the slurry obtained in a typical hydraulic dredging operation in order to determine the concentrations of contaminants released from sediments to the water.

Elutriate tests of sediment from Sturgeon Bank (Morrison et al., 1975) and Roberts Bank (Beak Consultants Ltd., 1977) showed only a release of iron and zinc. All of the other metals tested remained basically unchanged in the elutriate compared to the receiving water. Amongst the most thorough examinations of toxic contaminants release from dredged materials taken from a wide variety of locations throughout the U. S. is the work of G. F. Lee, at the Centre for

Environmental Studies, University of Texas. Using a modified version of the standard "Elutriate Test", Lee et al. (1975) found that manganese is the only heavy metal consistently released from dredged sediments. The other heavy metals such as iron, nickel, cadmium, mercury, copper, lead, zinc and chromium were either not released or relased in amounts too insignificant to affect water quality. The principal reason for the low release of trace metals from dredged material disposed in open water is thought to be related to the strong adsorption capacity of the suspended sediment itself, especially under oxidizing conditions and particularly in the presence of effective trace metal scavengers such as iron hydroxides.

It would appear then that based on the existing sediment water conditions prevailing along the pipeline route and based on the previously mentioned anticipated physico-chemical conditions expected during dredging, release of trace metals from dredged sediments should not be of sufficient magnitude or duration to appreciably alter water quality conditions.

3.2.6 Nutrients

The release of nitrogen and phosphorus compounds from dredged sediments may be considerable especially in the Brunswick Point shore approach area where marsh soils contain nutrient levels well above those found along the sandflat or Canoe Pass portion of the pipeline route (Table 2.4-4). Average nitrogen and phosphorus concentrations of sediment samples from Brunswick marsh are four and two times greater respectively than in sediments sampled along all other locations of the pipeline route.

A pertinent example of the potential amount of nutrient release expected for sediments along the pipeline route is available from elutriate tests of Sturgeon Bank sediment samples which showed total phosphate levels increasing an average of 0.30 ppm and ammonia increasing by 0.25 ppm (Morrison et al., 1975). The effects of increased nutrient loading due to the dredging activities would be most pronounced close to the point of discharge and during the infrequent periods that the bathtub is temporarily isolated during low spring tides. Rapid dilution of nutrients in the discharge plume and the high turbidity levels would probably preclude any response in the water column by phytoplankton capable of utilizing any available forms of nitrogen or phosphorus.

3.2.7 Ammonia and Sulphides

Dredged sediments which are inclined to release large amounts of nutrients such as may be the case for marsh soils at Brunswick Point shore approach may also present a potential problem with respect to the release of ammonia and hydrogen sulfide, both of which are quite toxic to aquatic organisms. For example, ammonia is toxic to salmon at 15 ppm, with the non-ionic form (i.e. NH_3 or NH_4OH) being the most toxic at concentrations as low as 0.4 ppm (Lee et al., 1975). However, although a source of ammonia is potentially available, especially in anoxic soils, it seems unlikely that hydraulic and physico-chemical conditions conducive to the accumulation of toxic concentrations of ammonia would occur in the water receiving the dredged material discharge. Levels of undissociated ammonia in the Fraser river increase with a rise in water temperature and pH. Therefore, in order to reach the previously indicated toxic level of 0.4 ppm, total ammonia concentration of 1.5 ppm would be required at a water temperature of 20°C and pH of 9.0 (Drinnan and Clark, 1980). Based on the information reported by Drinnan and Clark (1980), temperature, pH and total ammonia concentrations in the receiving waters of Canoe Pass very rarely reach the conditions necessary for the toxic accumulation of unionized ammonia. Moreover, measured sediment pH values in Brunswick marsh were less than 7.4 (Table 2.2-3).

The anaerobic environment that favours the production of ammonia in marsh soils will similarily produce hydrogen sulphide via sulphur reducing bacteria, especially in marine situations where there is a plentiful source of sulfate in seawater. Fortunately, however, most of the reduced sulfur in marsh soils is stored as nontoxic, relatively inert pyrite (FeS_2) (Howarth and Teal, 1979). The relatively small amounts of soluble sulfides present in marsh soil, although toxic in even minute amounts* oxidize very rapidly to harmless sulfate. Therefore, in order for soluble sulfides to become a significant concern in dredging operations, sulfide concentrations in the dredged material would have to approach contaminated levels of several hundred ppm or liberated soluble sulfides would need to become entrained into an anoxic water mass. It is apparent that neither of these two conditions would likely be encountered during dredging of the shore approach at Brunswick Point. Measured soluble sulfide concentrations in sediment samples were below 3.5 ppm and the discharged dredged material should be rapidly diluted by the flushing effects of tides and Canoe Pass currents.

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* Sulfides at concentrations as low as 0.20 mM (6.8 ppm) have been shown to kill marsh plants (Howarth and Teal, 1979).

3.2.8 Mitigative Measures and Residual Impacts

Most mitigative measures pertaining to water quality effects of dredging and open water disposal are either not applicable to this project (i.e. dredged material containment and silt curtains) or have already been included in Monenco's (1981) technical description of the construction methodology (e.g. discharge nozzle position and splash plate to reduce turbidity effects). Most of the remaining water quality impacts discussed in this section appear to be relatively minor, of short term duration and generally unavoidable.

3.2.9 Scheduling

Scheduling of dredging activities may have some overall effect on the difference in concentrations of water quality parameters between background levels in the receiving water and levels associated with the discharge plume. For instance, turbidity impacts would be less apparent during May through June, when natural background suspended sediment levels are highest in the estuary, than during the remaining months. Similarily, effects of dissolved oxygen reduction would be least apparent in winter when the relatively cold estuarine water is well saturated with dissolved oxygen. However, none of the water quality impacts described in this section appear to be of sufficient magnitude to warrant the curtailment of dredging for a particular month or season.

3.2.10 Release of Hazardous Chemicals

A number of hazardous chemicals associated with various aspects of pipeline construction could potentially interact with the Roberts Bank ecosystem resulting in varying degrees of toxicity to aquatic organisms.

Petroleum Hydrocarbons: Most of the heavy machinery as well as compressors and generators will require diesel fuels, hydraulic fluids, lubricants, etc. A potential risk of spillage exists mainly during maintenance and refueling procedures. An asphalt or coaltar based mastic will be used to cover each pipeline weld joint. This substance is usually applied as a hot liquid and therefore toxic substances may be released.

Fusion-bond Epoxy: Pipeline weld joints may be spray painted with an epoxy which is often "baked" on at high temperature after application.

X-Ray Chemical Agents: Each welded joint will be inspected with X-Ray photography and the photographic plates are developed on site. Wet chemical developing procedures would be used to run exposed film through chemical solutions in developing, stop bath, and fixing stages.

Corrosion Inhibitors: During hydrostatic testing of the pipeline, a biodegradable organic (amine) corrosion inhibitor may be used to protect the inside surface of the pipeline against attack by H_2S, CO_2 and organic acids. A liquid oxygen scavenger chemical (sulphite product) is often used in conjunction with the amine. Since hydrostatic fluids would be discharged at the foreslope, a potentially negative interaction exists with aquatic organisms occurring near the discharge point.

It is essential that for all of the above chemical products, proper care and handling is used in storage, transport and use to avoid contamination of water and sediments in the Roberts Bank ecosystem. Proper facilities for the containment and treatment of human waste must also be available to the entire construction crew. Appropriate containment and clean-up equipment and procedures should be available throughout the pipeline project in the event of accidental leaks or spills.

3.3 Marsh Habitat

3.3.1 Excavation

Within the total 120m wide working area reserve, consisting of 24,000 m^2 of marsh, approximately 8,500 m^2 or 35% will be excavated by both land and marine based equipment. Surface material containing plant roots and rhizomes would be retained separate from sub-surface dredged material.

If shoot growth is present during shore approach excavation, as would be the case in a seawards construction sequence, there would be rapid die-back due to burial or other physical injury. However, the majority of the plant species in Brunswick marsh are seasonally deciduous aboveground with belowground perennating organs. The premature loss of aerial shoots would thus be of little consequence provided that belowground organs remain alive.

Because excavation activities in the shore approach area result in the total removal of marsh habitat, the degree of impact can only be gauged by the success of restoring the area after backfilling. Most of the existing environmental factors should favour successful restoration and recovery of the excavated and backfilled area. For example, the total disruption is relatively small in area and short in duration. Also the area is flanked by natural marsh on both sides which serves as protection and as a source for plant colonization and recruitment. With proper and careful procedures during construction and restoration (detailed in section 3.3.4), new plant growth can be expected during the subsequent growing season.

Successful restoration and full recovery of the disturbed area depends on the operational definitions of "success" and "recovery". "Successful restoration" would be measureable as plant height, density and biomass levels approaching those of surrounding undisturbed marsh vegetation. Most important of all, the substrate must be stable, back to its original topographic relief, and properly drained (without ponding of water or otherwise impeded drainage).

"Full recovery" can be defined as the stage at which secondary succession is complete. The operational definition of "full recovery" is somewhat more elusive since most of the marsh consists of pioneer species and tidal marsh plant associations are in a constant state of flux. It is therefore difficult to predict the patterns of plant species groupings and associations which will emerge in successive years on the disturbed site. It is probably reasonable to assume that Scirpus americanus and Carex lyngbyei will continue to dominate the low marsh. In the high marsh however, several of the introduced grass and forbe species may dominate for some time by out-competing the native species currently established in the marsh.

3.3.2 Trampling and Smothering

During trench excavation a certain amount of trampling of vegetation will occur on either side of the trench (to a maximum "working area reserve" of 100m) due to movements of construction personnel and equipment. Vegetation on either side of the trench will also be subject to smothering as excavated material is sidecast and stockpiled for up to 21 days. If shoot growth is present during construction activities, much of the season's primary production could be lost. Damage to belowground organs is expected to occur mainly if deep tracks are made by heavy machinery. Effects of manual plug removal (10 x 15cm) and trampling in marsh areas of similar physiognomy to that encountered at Brunswick shore approach has been observed by Pomeroy and Levings (1980) to be evident for not more than about two months.

Plant smothering would be temporary underneath the spoil stockpile and within reach of the backfilling equipment. If spreading of stockpiled material occurs, some marsh areas within the working area reserve may become covered by sediment for longer periods of time. Experiments with the smooth cordgrass Spartina alterniflora have shown that there was no significant impedence of marsh growth after burial with dredged material (sand, silty sand, or clay) of up to 23cm depth (Reimhold et al., 1978). Lyngbyei's sedge grows within a total elevation range of ca. 1.25m, from mean sea level to slightly above mean high tide (see Figure 2.4-3). It would seem that the Carex marsh would probably tolerate shifts in elevation due to spoil burial provided that burial is of less than 20cm depth and is within the plant's natural elevation range.

3.3.3 Potential Pollutants

Because of the use of a variety of heavy machinery in the marsh area and near the dyke, petroleum hydrocarbons (diesel fuel, hydraulic fluid, etc.) may become a potential problem unless the utmost care is taken to prevent minor spills and leaks from equipment. Marsh soil has a relatively high adsorptive capacity and retains petroleum hydrocarbons for long periods. Weathering of impregnated oil would be extremely slow in poorly flushed and anoxic sediments. As a result, oil contaminated marsh habitats often require several years before new plant growth is again evident.

Several investigators have attributed this long recovery period to the slow, chronic release of toxic aromatics leached to the surface from buried oil (Hampson and Maul, 1977; Burns and Teal, 1979). Oil clean-up operations in contaminated marshes are difficult and destructive (Vandermeulen and Ross, 1977). It will therefore be essential that particular care is taken to prevent petroleum hydrocarbons from entering the marsh area.

3.3.4 Mitigative Measures and Residual Impacts

Certain precautions and proper construction techniques should be adopted in order to minimize the overall impact of construction activity in the marsh community. The following considerations describe mitigation measures and restoration techniques necessary to rehabilitate the marsh community after pipeline construction work is complete.

3.3.5 Scheduling

The most important and effective mitigation procedure at Brunswick Point shore approach would be to minimize the total construction time period and most important of all to limit the period of construction to a certain time of year.

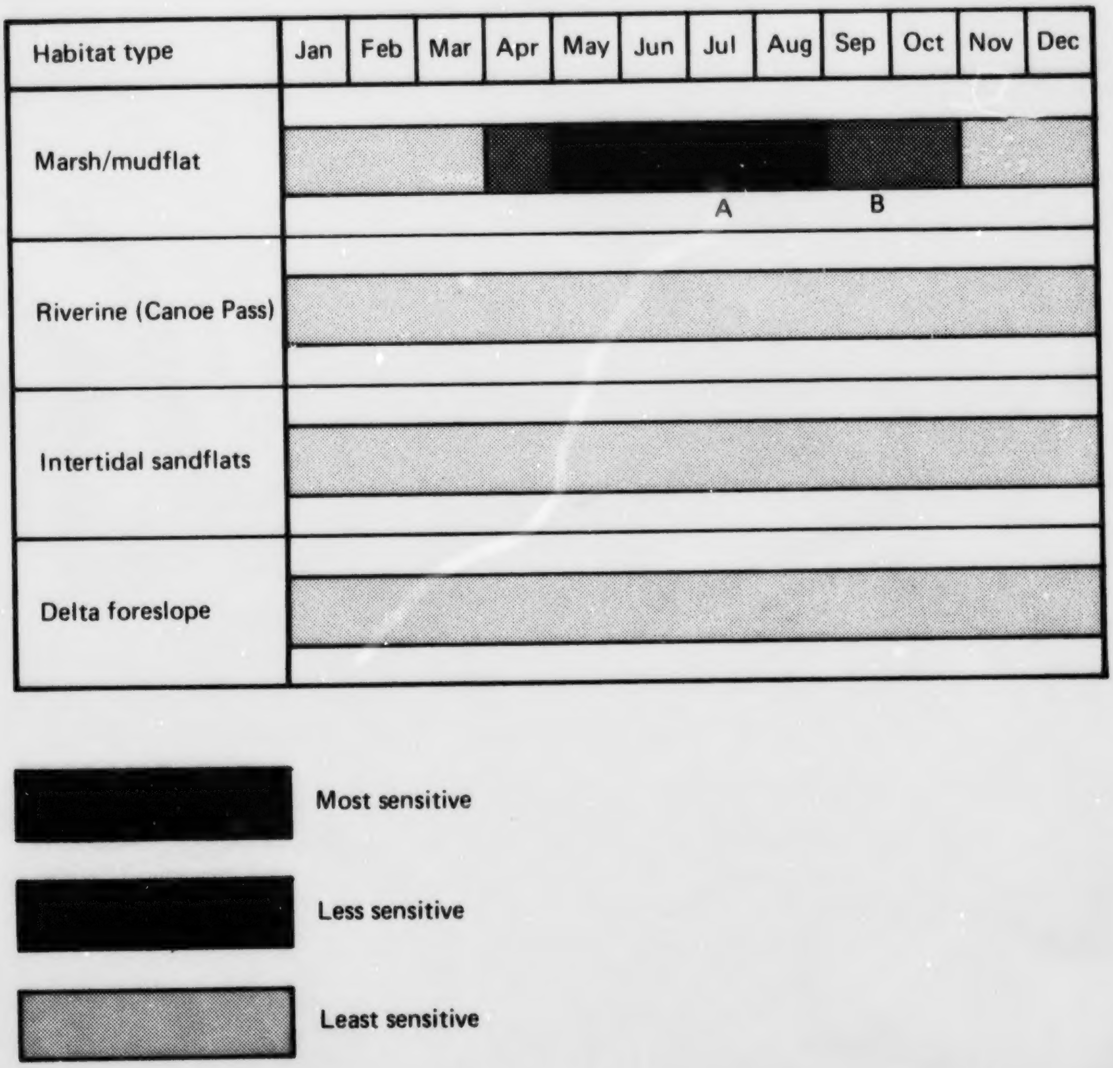
Based on the present knowledge of critical life history processes of dominant plant species in Fraser estuary marshes (described in section 2.4), it is suggested that construction activity impacts would be least damaging to the vegetation during the period of November through to March (Figure 3.3-1). During this time period aboveground growth will be in its natural die-back phase. Most importantly, belowground energy reserves will be fully replenished in preparation for the new growing season.

The landward direction of construction is by far the most preferred since the shore approach work would not occur until November-December.

Figure 3.3-1

Relative seasonal sensitivities of the tidal marsh habitat to physical impacts of pipeline construction.

A - Peak aboveground standing crop
B - Root and rhizome energy storage



3.3.6 Vegetation Survey

Plant community distribution and elevation should be accurately surveyed prior to construction so that surface material can be relocated close to its original position. Elevation contours every 0.25m would be sufficiently accurate for this task.

3.3.7 Surface Material Excavation and Stockpiling

It is essential that as much of the surface material as is possible (to a depth of 30 to 50cm) be separately stockpiled in order to retain the preserve the existing plant roots and rhizomes. Land based equipment should be used to remove surface material from the trench area before deeper excavation proceeds. The mechanical (or if necessary manual) method of topsoil removal should satisfy the following basic criteria:

(i) there should be control over depth of removal to approximately 35cm ± 15cm;

(ii) material should be stockpiled separately and protected against erosion or other physical damage;

(iii) the removed topsoil has to be accurately relocated to its original position in the marsh.

It is also advisable that plugs of root material be manually removed and stockpiled prior to excavation in case additional planting is required in sites of poor recovery.

Surface material should be stockpiled separately so that it does not become mixed in with or buried by excavated sub-surface material stockpiled on either side of the trench for use later as backfill. Dessication or freezing of roots and rhizomes may be a possible adverse effect of long term storage. However, it is anticipated that the total duration of work from excavation to backfilling should not exceed 45 days (Monenco, 1981). There is some preliminary evidence indicating that belowground organs of marsh plants can survive successfully for up to three months during winter while stored in a heap on land (Pomeroy, 1980).

It should therefore be feasible to store the stockpiled surface material for a period of up to 45 days in late autumn without any appreciable damage to the roots and rhizomes.

3.3.8 Backfilling and Restoration

It is anticipated that some of the spoil material may be lost via tidal action during the storage period (cf. Monenco, 1981). Imported material needed to compensate for a backfill deficit should be used near the bottom of the trench since the surface should be finished with the original organic layer stockpiled for final restoration. The residual volume of sidecast heaps of spoil material should be measured to determine the necessary volume of imported material.

The finished level should be within approximately ± 25cm of original topographic elevation at any given location. However, it is preferrable to remain slightly short of finished levels (by < 15cm) rather than overfilling the trench because:

1. most of the native marsh plants prefer slightly "wetter" conditions in comparison to the introduced weed species of the marsh which would be inclined to invade dryer, more elevated sites,

2. because the marsh is relatively sheltered, natural sediment accretion in low sites would be more likely to occur than erosion of elevated sites.

There is some preliminary evidence available about the feasibility and potential success of the restoration technique proposed above. Pomeroy (1980) describes a marsh transplant project in Deas Slough where sediment containing root and rhizome material was scraped from the surface of a marsh area in January using a front end loader and stored on land until it was placed at a transplant site three months later (in May). A diverse marsh dominated by _Juncus articulatus_ appeared soon after planting. Some difficulty was encountered with sediment stability because of the steep angle at which the transplant material was placed (S. Boyd, pers. comm.).

From the above preliminary evidence and based on our current understanding of the capacity of belowground energy storage in _Carex lyngbyei_ (Kistritz and

Yesaki, 1979) and Scirpus spp. (Hall and Hesaki, in prep.) it would appear that the dominant marsh plant species at Brunswick shore approach should respond relatively well after excavation, storage, and replacement. However, it is not entirely clear how the creation of a relatively irregular surface caused by cohesive clumps of material placed on the marsh surface will affect the restored marsh community. Nor is it possible to predict how well the newly restored marsh will withstand the erosive forces of waves and currents or, at worst, a severe winter storm.

3.3.9 Post-Construction and Restoration Monitoring

After backfilling and construction site clean-up has been completed, the entire working area reserve should be periodically inspected to monitor the condition of the marsh. If any sites remain with ponded water or impeded drainage, measures should be undertaken to clear these locations so that stagnant pannes* do not develop. A contingency plan should exist to rehabilitate any large sites where original restoration proved unsuccessful or in the event of excessive erosion or slumping of backfilled material. If this situation develops then it would be advisable to replant the bare sites with donor plants from stockpiled or adjacent areas in Brunswick marsh.

A post restoration vegetation survey should be conducted during the growing season of approximately three successive years to determine the overall response of the marsh community to the original restoration measures. This would give a measure of the success of marsh restoration. It would also provide the necessary feedback information needed to determine if any additional plantings or erosion protection measures should be undertaken.

In summary, residual impacts of shore approach excavation activities through Brunswick marsh should be relatively minor in view of the following considerations.

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* A marsh panne is a shallow pool of standing water devoid of vegetation or with dead and dying vegetation.

Actual construction activities in the marsh will last a maximum of not more than 1.5 months. Work can be scheduled to proceed during the approach of the winter dormancy period when the overall construction impact should be least damaging. Because of the relatively small area of disturbance, a simple and effective method of marsh restoration can be employed whereby original surface material containing roots and rhizomes can be saved, stockpiled, and returned to its original location. Recovery of marsh vegetation is thus envisaged to begin during the following growing season. With proper monitoring, any locations of poor recovery or sites damaged by severe winter storms, can be immediately dealt with by replanting with sprigs or plugs of marsh plants.

3.4 Benthos and Crabs

The potential environmental effects of the construction of a natural gas pipeline fall into three broad categories, each of which will be considered separately:

1. The effects of the excavation activity itself (i.e. hydraulic suction dredging, clamshell dredging and land based excavating) which will generally result in the destruction of benthic populations and the alteration of benthic habitat.

2. Effects of construction activities extending beyond the excavation itself into the remainder of the 200m working area reserve and beyond (e.g. disturbance and smothering of benthic habitat by construction and support vehicles, stockpiling of dredgate, creation of a plume of suspended sediments by backfilling operations).

3. The introduction into the benthic environment of potential pollutants (diesel fuels, lubricants, hydraulic fuels, etc.) either as a result of normal operation of construction equipment or from accidental spills.

3.4.1 Excavation

The excavation of the "bathtub" by hydraulic suction dredge is accomplished by the loosening of sediments with a rotary cutter, removal of material in a slurry by pump through a discharge pipe and redisposition as backfill at the back of the bathtub (Monenco, 1981). Inbenthic organisms in the path of the cutter head and epibenthic organisms closely associated with the bottom will be entrained in the process. Survival of such mechanical stress by benthic organisms is variable (Hirsch et al., 1978), but the combined effect of mechanical stress and subsequent burial at the disposal site will be the virtual decimation of the benthic population. For this reason, the main environmental concern for the benthos of dredged areas is with recovery of populations, rather than attempted mitigation of the mortality caused by dredging activity.

It is difficult to assess accurately the total loss of benthic biomass which will be caused by the proposed dredging. Calculations based on the total area within each benthic "zone" or habitat type to be dredged and approximations of the mean benthic biomass per m^2 within each zone are presented in Table 3.4-1. The total loss of benthic biomass to be expected is on the order of 2000 kg or approximately two tonnes. The total area of benthic habitat to be dredged in the intertidal portion of the pipeline route (45.0 hectares) represents 0.6% of the total intertidal sandflat area (Roberts Bank, only) of 6,848 hectares (Goodman, 1975). The standing crop disrupted by the direct effects of construction activities should amount to less than 1% of the benthic resources of the intertidal sandflats of Roberts Bank, assuming that the distribution of benthos along the ROB transect (Levings and Coustalin, 1975) is representative of the area.

The calculations of the potential loss of benthic biomass which were presented above do not include the Dungeness Crab populations which make seasonal use of Roberts Bank (section 2.5.1.7). To date, there are no good estimates of the abundance of crabs on Roberts Bank, although their patterns of migration onto the banks are understood in broad terms. Crabs will be present along the proposed pipeline route at two critical times during their life cycle (see Figure 3.4-1). Adult crabs migrate into shallow subtidal and lower intertidal areas from February to May (Hillaby, 1979). Moulting adults, "soft shells", usually occur from approximately early April to September. During this time adults are least

Table 3.4-1 Calculation of the approximate biomass of benthic organisms which will be destroyed by dredging the proposed pipeline across Roberts Bank.

Habitat		Total area to be dredged (m^2)[1]	Mean Benthic Biomass (g/m^2)[2]	Total Benthic Biomass (Kg)
Marsh/Mudflat		8,500	25.97[3]	220.7
Riverine		164,400	1.1	180.8
Sandflat	inner[4]	322,200	1.7	547.7
	outer	127,800	0.84	107.3
Slope		111,000	11.1	1,232.1
Total		733,900		2,288.6

[1] Calculated from Monenco (1981).

[2] Calculated from data in Table 12 (existing conditions section).

[3] This figure may be an overestimate based on single mudflat site at the edge of the marsh.

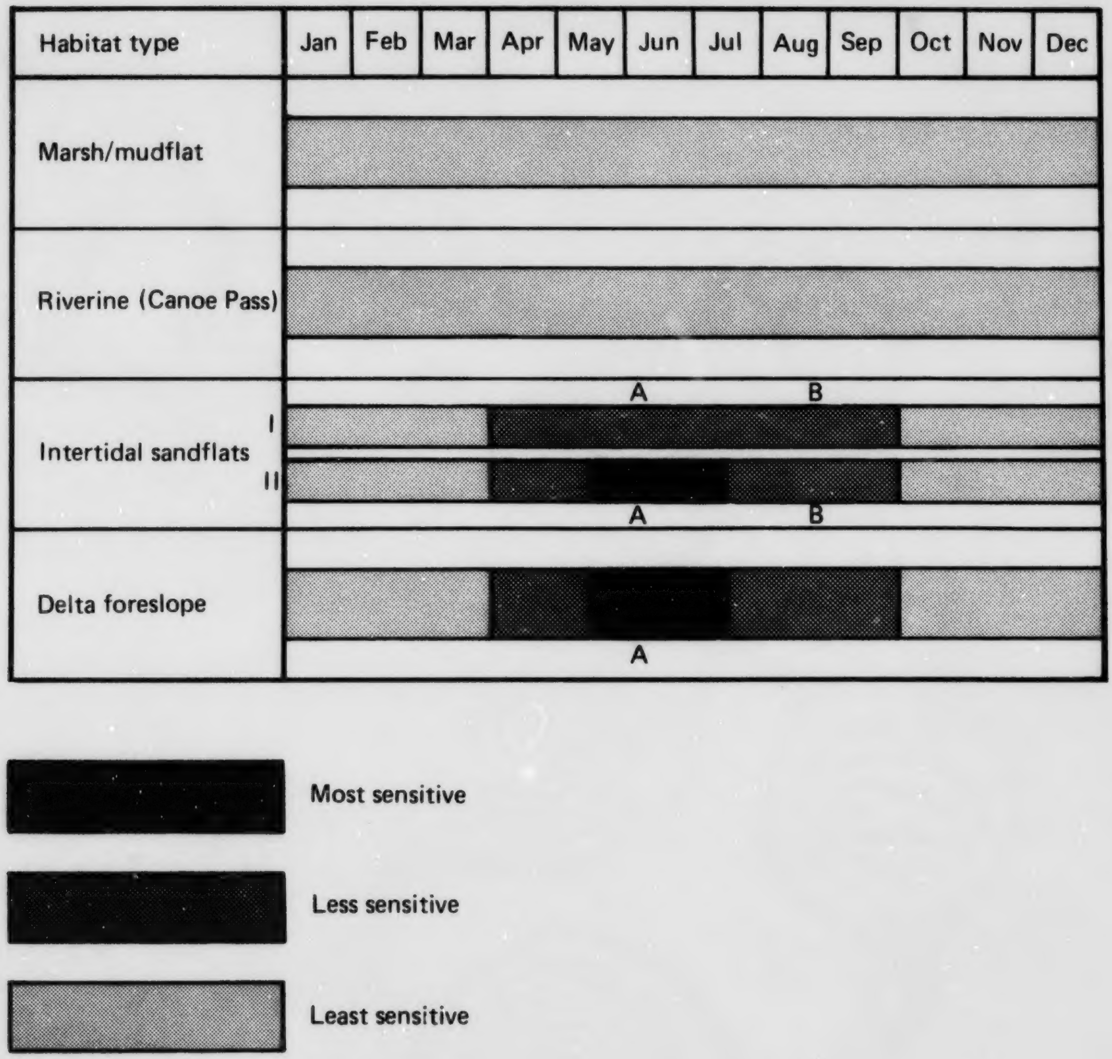
[4] Inner sites are those higher than 0.91m above chart datum; out sites are those below this elevation.

Figure 3.4-1

Relative seasonal sensitivities of crab populations to physical impacts of pipeline construction.

A - Crab moulting and mating
B - Juvenile settlement

I - Upper intertidal
II - Lower intertidal



motile and most vulnerable to mechanical damage. Generally from about June to about September, adult crabs are aggregated for reproduction in the shallow waters of the foreslope (Secter, 1979) and so could be affected by summer dredging in that habitat. The peak period of mating is thought to occur in June to early July mainly at depths between 1 to 15m below chart datum.

Small juvenile crabs first settle onto the banks in late August and September (Levings, 1980). Small crabs may not migrate to deeper waters with the adults, but spend their first winter on the intertidal sandflats buried to a depth of about 10cm in the sand (MacKay, 1942).

The effects of dredging activities on the resident Dungeness Crab populations have recently been the subject of an extensive investigation in Gray's Harbor, Washington (Stevens, 1981). Of the three types of dredges studied (clamshell, hopper, and pipeline), the pipeline dredge (a suction dredge with a rotating cutter head) was the most damaging to crab populations of sandy substrates; mortality caused by the dredge alone was estimated at 72%. The same dredge operating in silty sediments entrained very few crabs. Mortality of small crabs (< 66mm wide) was not addressed in this study, however survival rates increased as the size of crabs decreased.

In addition to direct damage caused the crab populations by the dredging equipment, the crabs will also suffer the temporary loss of an important benthic food source -the clams, shrimps and amphipods which will largely be destroyed by dredging activities along the pipeline route. This effect was observed in the Gray's Harbor study: areas which had been dredged three to four weeks prior to sampling were devoid of benthos and crabs. Areas which had not been dredged for at least a year had abundant benthic populations and normal densities of crabs (Stevens, 1981). On the other hand, dead organisms buried near the surface of the backfill could provide an unexpected feeding bonanza for the surviving crab population and shorebirds which feed on the benthos (Vermeer and Levings, 1977). Stevens (1981) observed large numbers of crabs feeding near an active dredge barge, and Rees (1978) described shorebirds virtually "following the plough" to feed on dredging disrupted intertidal benthos in the Lafan Sands, Menai Straits, Wales.

3.4.2 Disturbance Outside Direct Path of Excavation

The activities of the dredgers and support vehicles will cause disturbance of the benthic environment. These effects, such as trampling, smothering and exposure of the benthos by vehicles, anchors, etc., creation of a suspended sediment plume, burial of the benthos by backfilling in the bathtub, and stockpiling of dredgate will largely be localized in both space and time and should have a much smaller overall impact in the affected area than the total destruction of benthos which will be caused by the dredger itself.

(i) Disturbance and smothering of benthic habitat by construction and support vehicles; this category of effect encompasses a wide range of activities such as the moving of support anchors, dumping of spoil, delivery of pipe, stores and crew changes, groundings of barges and scows, etc. Monenco (1981) estimate the required "working area reserve" at 100m (total width, including excavation) in the marsh and 200m in the intertidal sandflat; they envision that equipment and spoil could be contained within this area.

Of the disruptive activities, stockpiling of dredge material is expected to cause the most damage. Most soft-bottom dwelling benthic organisms are motile and capable of at least some vertical migration through dredge spoil. Experimental evidence suggests that most epifauna do not survive burial; infauna showed varying "escapability" (Hirsch et al., 1978). Smaller organisms were most adversely affected. Mobility through sediments decreased at low temperatures and with increasing depth of overburden and survival was greatest when spoil was dumped on sediments of similar composition (especially sands on sands). Although some crustaceans were capable of vertical migrations through tens of centimeters (Hirsch et al., 1978), some local experiments (Chang and Levings, 1976) showed that Dungeness crabs (12 - 20cm carapace width) could not escape burial by 20cm of sand. The ability of the fauna to escape burial will also depend upon the duration of burial and possible toxicity of the spoil.

(ii) Creation of a plume of suspended sediments: The discharge nozzle will operate for three to four hours/day (at high tide) in a position raised some distance above the adjacent bank level (Monenco, 1981)*. During this period, losses of fine material into the water column as a suspension or "plume" will be 10 - 25% depending on the silt content of the sediment (generally less than 10% across the sandflat). Monenco (1981) has prepared a "worst case" prediction of the extent of the plume. The plume would extend up to 4.7 km in the direction of the tidal current and would be 1 km wide at its widest point. The concentration of suspended solids would vary from 400g/1 at the discharge nozzle to 25mg/1 at a distance of 4.7 km. Because the proposed route runs parallel to the direction of the tidal current, the most strongly affected area will be within the 200m wide working area reserve. By the time the plume will be as wide as the reserve, its concentration will be between 150 and 500mg/1, which is below the maximum concentration of 1000mg/1 which may be expected under natural, freshet condition.

Turbidity due to high concentrations of suspended sediments is a natural part of the Fraser as it is of many natural aquatic ecosystems. The resident flora and fauna of such systems are naturally adapted to turbid conditions (Hirsch et al., 1978). Increased suspended sediment loads can adversely affect the biota by:

(a) interfering with filter feeding;

(b) irritating and clogging fish gills, and

(c) shading, which decreases plant photosynthesis.

Indications are that suspended sediment concentrations typical of dredging activities are unlikely to have a lasting effect on a marine or estuarine ecosystem with the possible exception of coral reefs.

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* For the remainder of the day, discharge will be below local bank level, therefore suspended sediments should be largely confined to the bathtub during most of the operating period.

Extensive experiments on the physical and chemical effects of suspended sediments (both contaminated and uncontaminated) on a number of test species from a variety of phylogenetic groups were reported by Peddicord and McFarland (1978). Mortality in uncontaminated sediments was low for most species even when exposed for periods of days to concentrations up to 20g/1 (20,000mg/1). It should be noted that juvenile (3 to 4cm carapace width) Cancer magister were more vulnerable to sediment related stress while moulting (92% of all crab deaths were during moults; 34% of all crabs which attempted to moult, died) if exposed to very high concentrations ("fluid muds") of contaminated sediments for a period of days. Fluid muds (created by hydraulic dredging in fine grained sediments) may also cause high rates of mortality due to reductions of dissolved oxygen concentrations and/or the liberation of toxic hydrogen sulphide.

In conclusion, the concentrations of suspended sediments which will be created in the plume beyond the working area reserve, coupled with its low duration (maximum, four hours) indicate that the intermittant increases of suspended sediment conditions in the water column should cause no lasting effects on benthic organisms.

3.4.3 Potential Pollutants

During the period of pipeline construction a variety of potential pollutants such as diesel fuels, lubricants, hydraulic fluids, etc., may be introduced into the benthic environment. Since toxicity of such chemicals is a function of their concentration in the environment, the potential for contamination by these substances is greatest in the relatively enclosed marsh area and in the bathtub itself. During the crossing of the sandflat, strong tidal currents and wave action should dilute and disperse any potential pollutants. Spilled oils which are not quickly dispersed may be adsorbed by naturally occurring particulates. Once this association with the sediments occurs, the toxicants may adversely affect the local benthos and its predators over a period of years. If buried, such contaminated sediments may become biologically active if liberated by future dredging activity or natural sediment turnover (Hirsch et al., 1978). Due care must be taken during pipeline construction and testing to minimize contamination and in case of accidental spills, appropriate containment and clean-up measures should be taken.

3.4.4 Mitigative Measures and Residual Impacts

3.4.5 Scheduling

The construction of the proposed natural gas pipeline will not result in the permanent destruction or alienation of benthic habitat. Backfilling and restoration activities will provide "fresh" (that is, virtually uninhabited by fauna) substrate for colonization. This colonization coupled with subsequent *in situ* reproduction will eventually lead to the reestablishment of a benthic community, or "recovery" of the dredged area. The factors which determine the direction and rate of recovery of a benthic community following defaunation are complex. For a given community, there is generally no predictable sequence of recolonization. From field surveys of defaunated habitats, it has been found that recovery depends to a great extent on the nature of the adjacent, undisturbed community which must provide the potential colonists (from adult migration and/or juvenile settlement) (Hirsch et al., 1978). The fauna of naturally unstable substrates (such as exposed, intertidal sands) usually have life cycles which are well adapted to disturbance of the substrate.

Maximal rates of recovery of benthic communities are obtained if defaunation of the habitat is completed shortly before the seasonal increase of biological activity or larval abundance in the area (Hirsch et al., 1978). Recovery can be further enhanced by strong wave and current action which encourages adult dispersal into the affected area. From these considerations it is apparent that winter dredging may promote the most rapid recovery of benthic communities.

Since neither the landward or seaward construction schedule shown in Monenco's (1981) report proposes a winter dredging period, no preference is given to either.

Although part of the Dungeness crab population is present on the banks throughout the year, the time at which crabs will be most sensitive to dredging damage is while they are moulting, generally throughout the summer, and remain relatively immobile, buried for a period in shallow layers of sediment. During summer months in shallow waters of the foreslope habitat, crabs will also be aggregated for reproduction and, therefore, will be sensitive to mortality from dredging since entrainment rates are related to the crab density (Stevens, 1981). Dredging activities should, therefore, be least damaging to the crab populations if confined to a period from about September to April in shallow subtidal and lower intertidal areas along the proposed pipeline route.

Dredging activities would be least damaging to crab populations if the seaward schedule were followed since work in the delta foreslope and lower intertidal zone would occur before the sensitive moulting and mating period.

Significant crab populations are known to exist at the drop-off area of the foreslope (pers. comm. B. Hillaby, D.F.O.). Therefore, consideration will have to be given to the potential crab mortality that might occur as a result of dredging the foreslope trenches in December.

3.4.6 Possible Measures for Reducing Dredging Related Crab Mortality

In addition to scheduling construction to avoid major interactions with crab populations, several measures are suggested for mitigating dredging related crab mortality in case direct interactions with crab populations are unavoidable. Stevens (1981) provides the following suggestions:

1. "Physical disturbance of sediment in front of the draghead by a device similar to a plow or "cow catcher". If the upper 15cm of sediment could be pushed up and off to the side by such a device, crabs on the bottom surface and buried in the sediment might also be pushed out of the way, or at least alerted to the presence of the dredge."

2. "Bright lights displayed from the front of the draghead..."

3. A low voltage electric field around the cutter suction head may also act as a deterrent.

Mitigation techniques to be investigated by D.F.O. for the Roberts Bank coal port dredging project involve the use of underwater high frequency sound to frighten crabs away from the dredging operation. Consideration was also given to intensive pre-construction commercial harvesting of crabs to deplete populations prior to dredging. An alternative to the latter idea might to be close the crab fishery for one season in the general area of the dredging opeation in order to reduce the total cumulative impact on crab populations from both dredging and commercial harvesting.

3.4.7 Backfilling and Restoration

Maximum rates of recovery of benthic communities are observed in dredged areas where post-dredging sediment type is most similar to pre dredging conditions (Hirsch et al., 1978). The backfilling method described by Monenco (1981) would result in dredged material being deposited within 500 to 800m from from its original location along the intertidal flats. Backfill will differ physically from the parent material in three notable respects:

1. There will be some loss of silts and clays from the dredged material, although prevailing currents along the proposed route are such that suspended material should be dispersed along the route and into the "bathtub". In order to reduce the turbidity plume, Monenco (1981) recommended that a splash plate or conical expansion plate be attached to the discharge pipe. Because the discharge plate is one of the principal causes of crab mortality (and probably of the other members of the benthos, as well) in dredging operations, the latter device is preferable from an environmental viewpoint.

2. Backfill material will be relatively unconsolidated initially; however, it is anticipated that consolidation will occur quickly as backfilling continues (Monenco, 1981).

3. In order to allow for subsequent consolidation and settlement, the route will be backfilled to give a small (0.5m) hump above local bank level; irregularities in backfilling should be smoothed by wave and current action within a few days.

Within about a month after backfilling is completed at any given location, the substrate should be consolidated and suitable for benthic colonization. The change of grain size (toward a coarser substrate) and intertidal height will persist for a much longer period and could be considered residual impacts of the construction activity. Since benthic community structure is related to both intertidal height and sediment grade (Levings and Coustalin, 1975), a permanent change in either or both of these parameters could produce a different "climax" community (assemblage of organisms which is present and self-replicating after the process of community recovery is complete). The seasonal input of silt by the next Fraser river freshet should quickly make up the deficit in fine material, at least in the surficial sediment layer inhabited by the largest benthic populations.

3.4.8 Post-Construction and Restoration Monitoring

Trenching and excavation activities have been conducted on Roberts Bank in the past and have been the subjects of post construction impact assessments (B. C. Research, 1975 b, 1976 b; Levings et al., 1978). The proposed gas pipeline construction, although analagous to these cable laying projects in that no permanent alienation of benthic habitat should result, should itself be carefully monitored since it will affect a different type of benthic habitat (more dynamic) and also will defaunate a much greater area.

Monitoring of recovery of benthic communities following these previous dredging operations was, unfortunately somewhat limited in scope. B. C. Research (1975 b) sampled the benthic community over buried hydroelectric cables at Tsawwassen on a single occasion (the date of sampling is not given), presumably five years following cable burial. No major effects of the cables on the benthos at two tidal heights were noted. The other two studies (B. C. Research 1976 b; Levings et al., 1978) dealt with ditching and burial of hydroelectric cables across Roberts Bank in the late winter/early spring of 1976. Post-construction monitoring was confined to a few weeks after completion of construction activity. Levings et al. (1978) recorded depressed population densities in the immediate vicinity of the excavation. The excavation itself created a permanent depression in the mudflat in which plant debris collected. This in turn formed new substrate for colonization by amphipods and isopods. B. C. Research (1976 b) studied the same benthic population three weeks after cable burial. In spite of an increase in median substrate partical size from < 63μm to < 100μm, indigineous species of polychaetes and molluscs had already recolonized the scar and adjacent, disrupted habitat. The clam, *Macoma*, and several polychaete species increased to densities exceeding pre-construction densities, illustrating how rapidly recovery may occur in late winter/early spring.

These local examples indicate that recovery of the benthos following dredging should be rapid, however the zones affected were much narrower (on the order of meters) than will be the cse with the proposed pipeline project (on the order of 100 meters). The natural defaunation of Tampa Bay by a red tide in August 1971 affected an area (300,000m^2), comparable to that which will be affected by the proposed pipeline construction (Simon and Dauer, 1977). In this case, sediment grain size was not altered. An equilibrium assemblage was established after 11 months. Initial colonizers were the "opportunistic" polychaete species which have high dispersal activity due to adult mobility and pelagic larvae. Mollusc and amphipod species were slower to colonize and significantly affected by seasonal patterns of reproduction and dispersal.

In summary, the prospects for recovery for the benthic and crab populations of the proposed pipeline route are good. If dredging can be scheduled to proceed in fall and early winter, the critical summer period when crabs are moulting and aggregated for mating on the outer banks would be avoided.

Fall and early winter dredging is also best for the rapid recovery of the other benthic invertebrates of the proposed pipeline route. Initial invasion by adults will be facilitated by increased wave and current activity in winter, and subsequent colonization by settling juveniles in spring would occur within a few months after cessation of dredging. From previous studies in the Fraser and other ecosystems, partial recovery of the benthos is to be expected within a few months of disturbance with full recovery of an "equilibrium" community (and the resident crab population) requiring approximately one year.

Because no permanent alienation of habitat will occur and changes in substrate type will generally be relatively minor, no long term impacts upon the benthic community are anticipated. Since dredging operations in fall and early winter should have the least overall impact on benthos and crab, as previously discussed in this section of the report, the seaward construction schedule would be somewhat preferrable to the landward schedule.

3.5 Fish

The potential effects of pipeline construction on Fraser fish stocks fall into three categories:

1. Direct effects of dredging through the entrainment of fish into the cutter suction head, and the obstruction of migration pathways.
2. Indirect effects of construction activities, arising chiefly from the destruction of benthic communities which may serve as an important food source for fish.
3. Indirect effects of dredging activities which may degrade the water quality of the habitiat.

3.5.1 Suction Dredge Entrainment and Obstruction

The operation of hydraulic suction dredges in the Fraser river channels and marshes in spring carries a high risk of resulting in the capture (entrainment) and destruction of migrating juvenile salmonids. Because fry and smolts have poorly developed avoidance capabilities (Philpott, 1978), the number entrained is proportional to their density in the path of the dredger. The experimentally determined mortality rate of fry which are entrained is 98.8% (Dutta and Sookachoff, 1975). In recognition of the probable impact of dredging activities on juvenile salmon migrants, the Department of Fisheries and Oceans established dredging guidelines for the Fraser river to minimize this impact (Anonymous, 1976).

The general dredging restrictions for suction dredges in the mouth of the Fraser River apply to the period from mid-March to the 1st of June. These guidelines have been imposed to protect the peak of downstream fry migration when as many as two billion anadromous fry pass out of the lower Fraser river into the Strait of Georgia.

It is important to recognize, however, that the timing of fry migration can and does vary from year to year depending on flow regimes in the Fraser River as well as numerous other environmental determinants. For example, fry migration data from Mission can be used to calculate the likelihood of encountering chum, chinook or pink fry at any given time of the year. Data from 14 years of monitoring (Figure 3.5-1) show that after the first week in March migrating fry were present in over 50% of the 14 years examined. The onset of fry migration in the last two weeks of February occurred in less than 15% of the 14 years. Fry migration in the first half of February is either very rare (chum) or absent (chinook, pink).

The occurrence of large numbers of pink juveniles in even numbered years as well as the large adult pink salmon runs in odd numbered years will also have to be taken into consideration once a given year is targeted for construction.

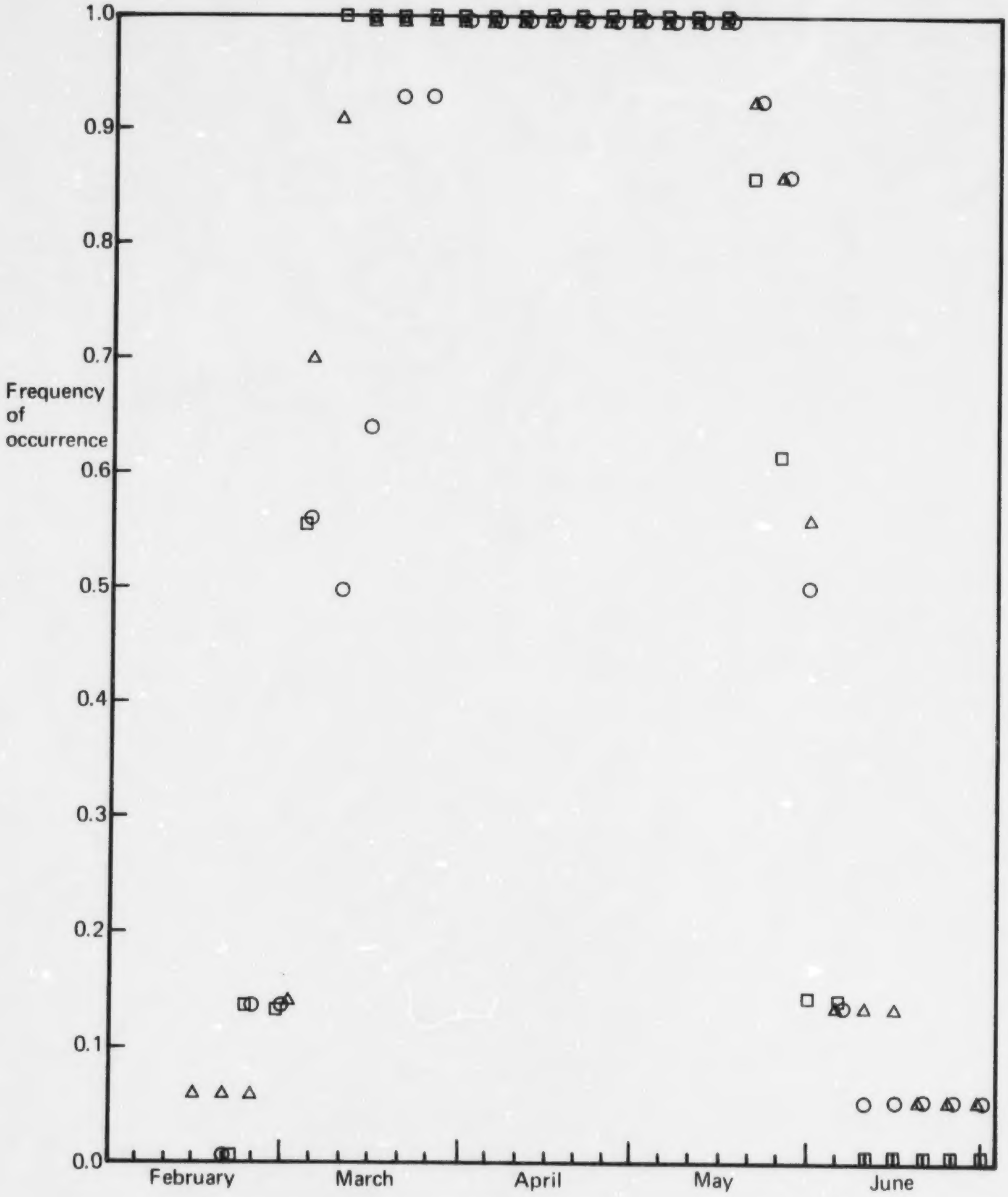
Because of their extremely limited power to escape the dredger, highest numbers of fry would be entrained in habitats where they occur in the highest densities. From the work of Levy et al. (1979), Levy and Northcote (1981) and Goodman (1975) (described in section 3.5) it is apparent that the most sensitive habitat will be the marsh creek systems, followed by Canoe Pass itself (where the outmigrants will be relatively concentrated due to the narrowness of the channel). The bathtub created by the dredging operation may also be a potential site of relatively high fish concentration. Both residence times and densities are likely to be much lower on the sandflats where fry should be more widely dispersed.

Although adult, upstream migrants should be able to avoid the suction dredges, the operation of the dredge train in Canoe Pass in late summer/early fall could cause delays in the upstream migrations even with only a partial obstruction of the total channel cross section. Monenco (1981) have estimated that the dredge, laybarge and backfill pontoon would occupy Canoe Pass for up to 43 days. There is direct evidence suggesting that salmon migration in river channels is controlled by habitat recognition and position learning (Ellis, 1962). In other words, salmon migrate through only a fraction of the total water space available to them. Following this assumption then, salmon fixed to a Canoe Pass migration route may be delayed for as long as the dredging operation obstructs their specific migratory pathway. Under a worst case situation, a delay of up to a month would, of course, almost eliminate the chance of successful spawning.

On the other hand, it is quite evident from observations of migrating salmon populations encountering natural obstructions that salmon populations have

Figure 3.5-1

Likelihood of finding salmon fry along the proposed pipeline route at any given 5-day interval between February 1 and June 30. (based on fry data at Mission, 1965 - 1978, DFO)



	Average population median	Average population peak
○ Chinook	April 16	April 16
△ Chum	April 18	April 19
□ Pink	April 26	April 22

Even numbered years for pink fry calculated over entire 14 year period, 1965 - 1978.

evolved mechanisms to deal with uncertain events along their upriver migration. Therefore the migrating salmon which encounter the dredging related obstruction at Canoe Pass would either comprise only a proportion of the total stock in that particular run or would seek an alternate entrance into the Fraser river. In either case, the net impact of the dredging on the salmon run would be minor barring any direct intake of fish into the cutter suction head.

In addition to the important commercial species, a number of fish species of minor or no commercial importance inhabit the area of the proposed pipeline route. Overall, fish densities on the sandflats north of Canoe Pass are relatively low compared with other parts of the Fraser delta (Goodman, 1975; Greer et al., 1980). The most abundant species in the vicinity of Canoe Pass are Starry flounder and staghorn sculpins (Greer et al., 1980); both species live closely associated with the bottom and feed largely on the benthos and so should be susceptible to dredging damage. In Grays Harbor, Washington, staghorn sculpins in particular were entrained in large numbers by the pipeline dredge Malamute operating between September and November (Stevens, 1981).

The bathtub created by the proposed dredging operation will be a temporary, but potentially important, man-made topographic feature on the delta flats. Since high catches of a number of fish species were recorded in a similar, although larger, depression on Sturgeon Bank, the "Sturgeon Pit", and the "borrow pit" at the Roberts Bank coal port (Greer et al., 1980), the bathtub could conceivably become another such low tide refugium, especially if food organisms become concentrated there. This is of concern since fish residing in the bathtub would be vulnerable to direct intake into the cutter suction head or encounters with areas of high suspended sediment. On the ebb tide, fish follow the dewatering channels through the marshes and across the tidal flats (Levy and Northcote, 1981), and so the introduction of fish into the bathtub will probably be even greater when drainage channels are bisected.

Loss of Potential Food Sources

The effects of the proposed pipeline construction on the benthic resources of Roberts Bank were fully covered in the preceeding section. The localized destruction of benthic communities and the subsequent food web disruption will be an indirect effect of the pipeline construction on the estuarine fish populations.

Several factors indicate that the effect on the commercial fish populations should be minor, if not negligible. First, it was estimated in section 3.4.1 that the loss of benthic biomass should amount to less than 1% of the benthic standing crop of Roberts Bank. Secondly, because the band of destruction of benthic communities will be relatively narrow and the fish populations are highly mobile, they can move to undisrupted areas off the route to feed. Finally, from what is known of the food of fish on the sand flats, it is apparent that the majority of their diet consists of larval and juvenile fish, and motile epibenthic and pelagic crustacea. Abundances of these prey are not likely to be noticeably affected by pipeline construction activities. One exception to these generalizations is the Starry flounder which feeds on the benthos and so could be adversely affected through the loss of food.

3.5.3 Potential Degradation of Water Quality

Dredging related degradation of water quality will be most pronounced close to the dredge and backfill operation, particularly in the bathtub when isolated by low tides. However, even under the worst case situation when the bathtub is temporarily (maximum three hours per day) isolated at low tide, the only major potential problem existing in the main isolated water mass pertains to high levels of suspended sediment. All other effects of dredging on water quality discussed in section 3.2 are considered to be relatively minor and should therefore not pose a serious threat to fish which may temporarily encounter the plume created by the dredging operation.

Experimental results on the temporary exposure of fish to suspended dredged material show that adverse effects to fish are highest when sediments are polluted or high in organic content and fine particulate material (Peddicord and McFarland, 1978). Estuarine fish exposed to unpolluted sediments were able to tolerate high suspended sediment levels (up to 1.5g/l) for up to 21 days without mortality.

Since the intertidal flats along the proposed pipeline route are subject to frequent tidal flushing, fish in the immediate area of the discharge plume would have good opportunity to avoid the plume entirely. Fish residing in the bathtub would be trapped for only short durations at low tide. Moreover, methods can be used (described in section 3.5.6) to encourage fish to leave the bathtub at high tide or to discourage fish from entering it.

3.5.4 Mitigation Measures and Residual Impacts

3.5.5 Scheduling

Scheduling of dredging to avoid the period of downstream fry migrations and the peak adult spawning runs should reduce the direct impacts of pipeline construction on the salmonid populations to a negligible level. Based on the information provided in section 2.6, Figure 3.5-2 summarizes (diagramatically) the scheduling constraints suggested by environmental considerations pertaining to the major fishery recources of the estuary. Taking into account the most important fish component of the estuary, (migrating salmon fry and adult spawning runs), the dredging schedule should avoid the marsh and Canoe Pass area from mid-March to early June and Canoe Pass from early August to late October.

Considering the above environmental constraints on the dredging schedule, the landward schedule is preferred over the seaward schedule.

3.5.6 Suction Dredge Entrainment and Obstruction

Because fish are present in the estuary throughout the year, some fish mortality as a direct result of construction activities is inevitable. Concentration of fish in the bathtub is of particular concern for reasons previously described. Noise and vibration associated with the dredging operation itself may be sufficient to repel fish. However, when operations are suspended for any reasons, it is possible that fish may be attracted to the bathtub by the increased abundance of prey organisms dredged out of the sediment. Although it is difficult to postulate exactly to what extent fish may become concentrated in the bathtub, it is recommended that certain safeguards be implemented into the dredging operation to minimize the probability of an accumulation of fish in the bathtub and to generally discourage fish from it.

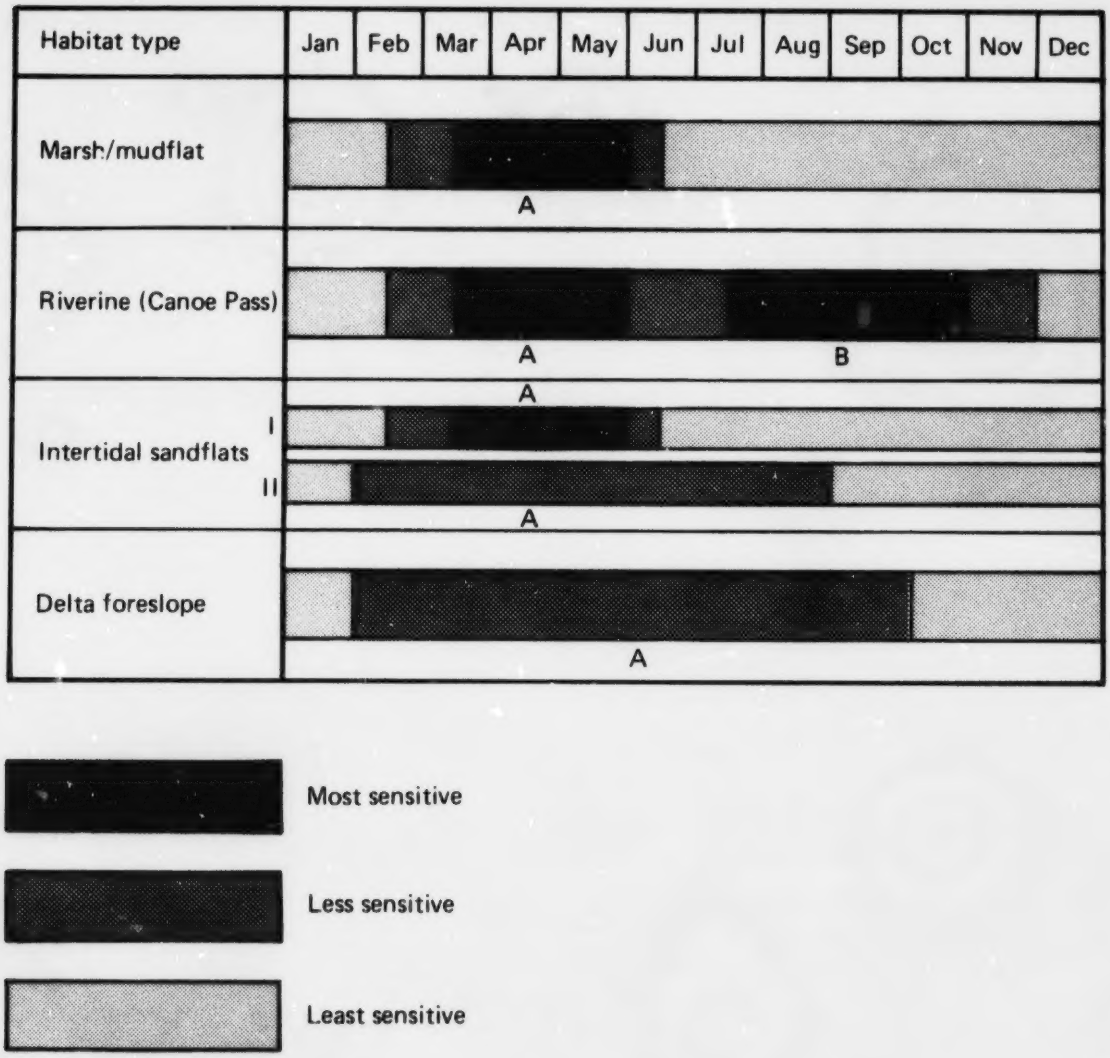
When dredging is resumed after a "shut-down" period it is advisable to turn on engines, compressors, the cutter head, and any other "noisy" equipment before the suction pumps are activated on the dredger. In this way, fish will have an opportunity to leave the general area close to the suction intake. Suction pumps on the dredger should also be shut off whenever the cutter suction head is

Figure 3.5-2

Relative seasonal sensitivities of salmon to physical impacts of pipeline construction.

A - Salmon fry and smolt migration and rearing
B - Major salmon spawning runs

I - Upper intertidal
II - Lower intertidal



raised from or lowered to the bottom to avoid suction intake in the water column. These types of dredging procedures are usually familiar to dredging contractors with some past experience in the Fraser river and should be addressed in dredging tenders issued by B. C. Hydro.

Other tyes of fish deterrents which should be considered are: chemical repellents (bear paw extracts), induced electric field (low voltage currents), and, possibly, "bubble curtains" (using air compressors) around the dredger.

Some of the above ideas were suggested by P. Ryan (D.F.O.). Future discussions with D.F.O. personnel and dredging operators with local experience will undoubtedly reveal additional innovative techniques.

As discussed previously, fish follow dewatering channels when leaving the banks during ebb tides. It is critical, therefore, that these channels not be blocked during construction and that backfilling restore channel morphology as close as possible to the original configuration.

3.5.7 Residual Impacts

Anticipated residual impacts of pipeline construction on fish populations of the estuary (mainly Starry flounder) are indirect effects due to the disruption of benthic food webs which may require up to one year to recover to original biomass levels. Since fish are present in the estuary at all times of the year, some mortality is inevitable when fish (particularly sculpin) are caught near the cutter suction head.

4.0 MONITORING AND ASSESSMENT

There are three main considerations for environmental monitoring appropriate to this project:

(i) The restoration of the vegetation community at Brunswick marsh shore approach.

(ii) The natural recovery of the benthic community along the backfilled pipeline route.

(iii) The entrainment and mortality of fish and crabs via dredging.

Monitoring the restoration of Brunswick marsh shore approach and the benthic recolonization of backfilled areas across the intertidal sandflats would involve pre- and post-construction surveys. Monitoring of fish and crab entrinment and mortality would proceed during the dredging operation itself.

Environmental monitoring and assessment of this project is considered to be of value since it can be used to determine the merits and effectiveness of mitigation techniques such as the various fish deterrents recommended for the dredging operation in the bathtub. Moreover, the above three considerations for environmental monitoring would also provide important case history information for use in future environmental impact assessments dealing with physical disruptions of the tidal flat substrate.

Monitoring of restoration in Brunswick marsh shore approach is considered to be the main monitoring activity of direct benefit to this project. Monitoring of benthic recolonization and fish and crab entrainment are suggested primarily because of their possible interest to various resource management agencies and to advance the scientific basis for environmental impact assessment in the Fraser estuary.

Monitoring of the vegetation community at Brunswick marsh shore approach before, during, and after restoration is considered an essential part of the restoration effort since biological information will be needed to ensure that restorative measures used have been adequate and effective. A pre-construction survey will be needed to accurately measure the location and elevation of vegetation to be removed for stockpiling. During construction, the removal, stockpiling, and backfilling of vegetation should be supervised to ensure that the root and rhizome material is dealt with in a proper manner. After restoration, the vegetation community should be measured against a control plot (adjacent undisturbed sites) to determine the success of restoration and to provide the necessary feedback information needed to determine if additional plantings or erosion protection measures should be undertaken.

Information concerning the natural recovery of benthic communities after dredging and backfilling will be of value in providing case history information for use in future environmental impact assessments pertaining to the disruption of the Fraser estuary tidal flats. This type of information would also be especially helpful in assessing the environmental impact of a repair procedure in the remote chance that one of the pipelines failed a hydrostatic test.

To facilitate observations of post-dredging recovery of the benthic community of the proposed pipeline route, a well-designed preliminary survey should be undertaken. Permanent sites should be established in each of the habitat types and sampled prior to the initiation of dredging. Several deficiencies of previous studies on Roberts Bank should be corrected with this preliminary survey:

1. Sampling should be carefully replicated at each site so that data may be analysed statistically.

2. Seasonal variations in the benthos should be documented prior to dredging so that dredging effects may be separated from seasonal effects.

3. Sample design should consider the elements of the food web which have been particularly understudied in the past, specifically, the meiobenthos and the epibenthos of the sandflats.

A post-construction survey of the benthic community of the proposed pipeline route should be undertaken to determine rates of recovery, and to document any possible long term residual impacts on the community. A monitoring program should be designed to determine for each habitat type:

1. The immediate effects of construction activities (i.e. within one to three weeks of backfilling).

2. The pattern of natural community re-establishment over one to two years to allow for seasonal recruitment effects.

3. A follow-up survey after several years to determine whether there are any long term residual impacts.

The results of such a study will provide invaluable, site specific data for assessing future dredging related developments within the estuary.

Measuring the entrainment rate and mortality of fish and crabs in the dredging process would be useful not only in providing case history information but also in assessing the value of techniques used during construction (e.g. chemical repellents, or dredging techniques to minimize entrainment). Several techniques to monitor fish entrainment and mortality would need to be improvised and tested to suit the specific field conditions encountered during dredging.

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APPENDIX 6.2 Laboratory Procedures and Quality Control Measures Used in Analysing Sediments Sampled Along the Proposed Pipeline Route

METHOD OF TESTING

Outlined below is a brief description of the analytical methods used on sediment samples submitted to Can Test Ltd.

pH - determined by specific ion electrode after making a slurry with distilled water (1 part water: 1 part sediment).

Moisture - determined gravimetrically after drying sample overnight at 103°C.

Loss on Ignition - determined gravimetrically after ashing sample at 950°C for one hour.

Particle Size - analyzed in accordance with procedures described in Ocean Dumping Report #1, "Methods for Sampling and Analysis of Marine Sediment and Dredged Materials", edited by A. Walton, Dept. of Fisheries and Environment, Ottawa, 1978.

Total Carbon - determined by Leco Induction Furnace.

Total Nitrogen & Total Kjeldahl Nitrogen - analyzed in accordance with procedures outlined in "Official Methods of Analysis of the Association of Official Analytical Chemists", 13th Edition, 1980.

Chemical Oxygen Demand - analyzed in accordance with procedures set out in the "Methods for Sampling and Analysis of Marine Sediments and Dredged Materials", Ocean Dumping Report 1, February 1978, published by Fisheries and Environmental Canada with modifications as per "Seim-Micro Tube Methods for Chemical Oxygen Demand" R. R. Himebaugh and M. J. Smith, Analytical Chemistry, Volume 51, No. 7, June 1979 (only reagent strengths, sample sizes, and reaction vessels were modified).

Soluble Sulfide - was determined on a sodium hydroxide leachate, according to the procedures set out in Standard Methods for the Examination of Water and Wastewater, 14th Edition, 1975, published by the American Public Health Association with modifications from "The Determination of Sulfide with DPD", M. B. King, Journal of the American Water Works Association, October 1977.

Metals - samples were digested with a combination of nitric and perchloric acids and analyzed for the individual elements as follows:

Mercury - cold vapour atomic absorption
Cadmium, Lead, Copper, Zinc - direct flame atomic absorption
Arsenic - hydride generation atomic absorption
Manganese, Phosphorus, Iron - Inductively Coupled Argon Plasma

Pentachlorophenol - samples were tested according to a procedure described by Renberg, L., 1974. Ion exchange for the determination of chlorinated phenols and phenoxy acids in organic tissue, soil, and water. Analytical Chem. 46:459.

PCB, DDT and Derivatives - samples were tested according to "Procedures for the Analysis of Organochlorinated Pesticides and PCB's in Fish and Sediments", published by the Inland Waters Directorate, Water Quality Branch, Environment Canada, 1977.

Note: Polychlorinated biphenyls (PCBs) are sold as mixtures of the different isomers under the trade name Arochlor. The first two digits which follow the trade name refer to the class of compound (i.e. biphenyl, 12) and the last two digits refer to the weight percent of chlorine in the mixture. For instance a mixture of biphenyls containing 54% chlorine by weight is called Arochlor 1254. Only those isomers detected were reported.

Quality Control

Where applicable, duplicates, certified standards or analyte spikes were used to form the quality control program for this project. Outlined below is a more detailed description of these data.

Total Carbon

	% Carbon
Standard (Cert. 0.373%)	0.380
	0.377
	0.376
	0.379

Total Nitrogen

		% Total Nitrogen
Duplicates -	Sample #6	0.029, 0.028
	Sample #10	0.016, 0.015
	Sample #14	0.021, 0.019
	Sample #17	0.026, 0.031
	Sample #23	0.069, 0.075

Total Kjeldahl Nitrogen

		% Kjeldahl Nitrogen
Duplicate -	Sample #4	0.015, 0.018
	Sample #9	0.016, 0.015
	Sample #14	0.016, 0.017
	Sample #17	0.017, 0.021
	Sample #24	0.072, 0.077

Chemical Oxygen Demand

Recovery was calculated on 20% of the samples by spiking each with a known concentration of standard.

Spiked Sample #	% Recovery
4	107
8	100
19	98
22	100
24	104

A standard, certified at 200 (μg/g) was analyzed concurrently with the samples. These data are given below.

Trial	Results (μg/g)	% Recovery
1	204	102
2	206	103
3	196	98.0
4	206	103.
5	204	102.

Soluble Sulfide

		Sulfide (μg/g)
Duplicates -	Sample #1	L 1.0 , L 1.0
	Sample #4	L 1.0 , L 1.0
	Sample #8	L 1.0 , L 1.0
	Sample #17	0.66, 0.75
	Sample #20	0.20, 0.23

Metals

Over 50% duplication was used for the trace metal analysis. Below is an example of the results obtained for duplicates as well as certified standards.

SAMPLE	MERCURY	CADMIUM	LEAD	ARSENIC	COPPER	ZINC	MANGANESE	PHOSPHORUS	IRON
NBS STD-1645	1.2	9.4	720.	63.	112.	1680.	760.	1490.	10.1%
1645 CERT.	1.1	10.2	714.	66.	109.	1720.	785.	(1560.)	11.3%
STD-WQB 2	1.02	1.6	95.	23.	81.	273.	2270.	4510.	4.57%
WQB2-CERT.	1.1	1.6	95.	-	94.	287.	2400.	4210.	6.53%
SAMPLE #5	0.009	0.29	2.1	3.20	8.63	29.8	278.	936.	1.18%
SAMPLE #5-DUP.	0.014	0.28	2.0	2.79	8.50	29.9	288.	980.	1.21%
SAMPLE #10	0.030	0.82	1.9	4.83	12.7	40.3	273.	1220.	1.41%
SAMPLE #10-DUP.	0.036	0.73	1.8	4.94	12.9	42.9	269.	1215.	1.41%
SAMPLE #15	0.017	L 0.06	2.9	4.26	14.3	40.6	288.	1430.	1.68%
SAMPLE #15-DUP.	0.027	0.06	3.1	4.45	14.4	40.3	240.	1470.	1.70%
SAMPLE #20	0.043	L 0.06	3.6	6.23	16.2	42.4	348.	1680.	1.58%
SAMPLE #20-DUP.	0.050	L 0.06	3.5	5.96	16.2	41.6	338.	1750.	1.56%

1. PCB + DDT & Derivatives

Approximately 20 g of wet sediment was spiked with 0.40 µg each of DDT and related compounds and 2.0 µg of PCB. The samples were extracted and analyzed according to the procedures outlined below.

Compound	Sample #5 % Recovery	Sample #20 % Recovery
DDE	96	57
DDD	99	65
DDT	109	96
PCB	77	-

2. PCP

Aproximately 10 g of wet sediment was spiked with 0.40 µg of pentachlorophenol and was analyzed according to the procedures outlined below.

Sample #	% Recovery
1	97
19	72
22	84

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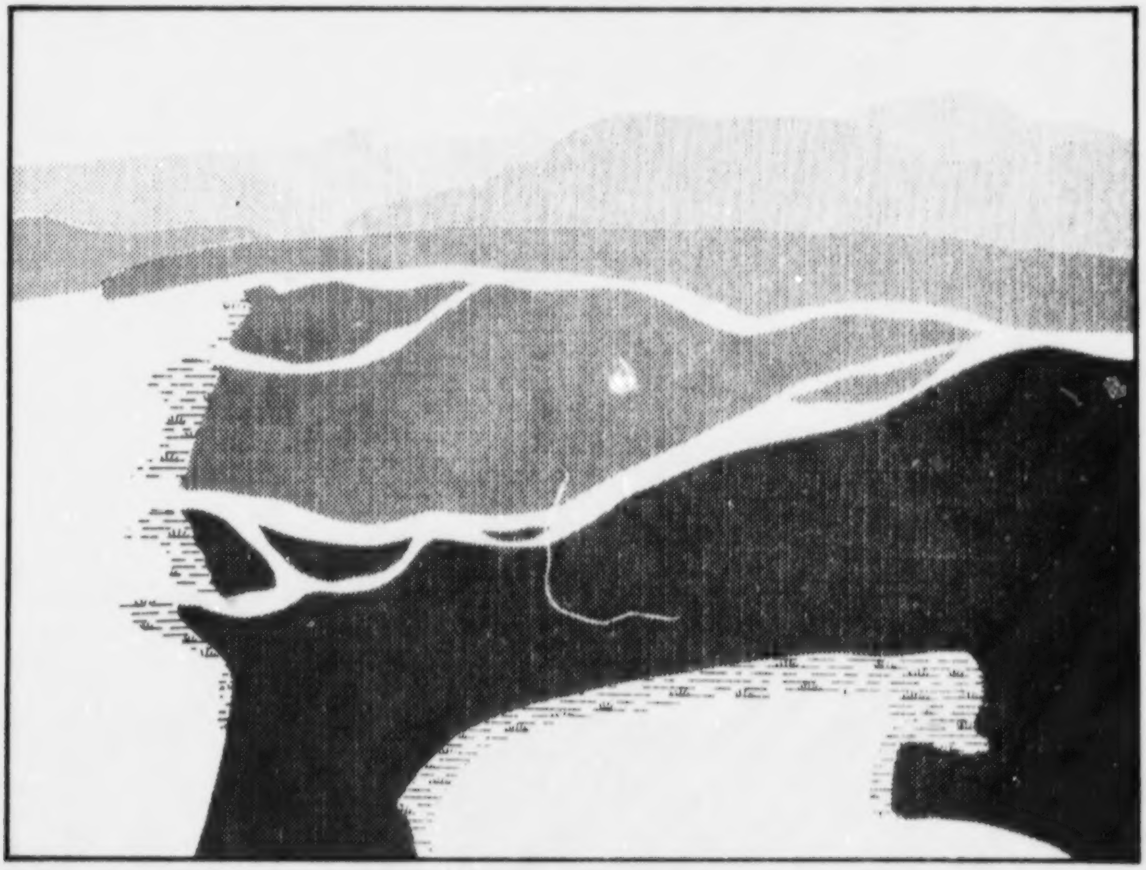
ENVIRONMENTAL IMPACT ASSESSMENT
OF
CONSTRUCTION
OF A NATURAL GAS PIPELINE
ACROSS ROBERTS BANK



Volume 4: Potential Impact on Wildlife of Pipeline Construction Across Roberts Bank

D.A. Blood & Associates

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ENVIRONMENTAL IMPACT ASSESSMENT OF CONSTRUCTION OF A NATURAL GAS PIPELINE ACROSS ROBERTS BANK

VOLUME 4

POTENTIAL IMPACT ON WILDLIFE OF PIPELINE CONSTRUCTION ACROSS ROBERTS BANK

B. C. HYDRO
FEBRUARY, 1983

DONALD A. BLOOD AND MICHAEL J. CHUTTER
DONALD A. BLOOD & ASSOCIATES

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EXECUTIVE SUMMARY

1. INTRODUCTION

Potential impacts on wildlife of construction of a natural gas pipeline across Roberts Bank were assessed. The evaluation is intended to satisfy the requirements of British Columbia Order-In-Council 908 with respects to wildlife. The report presents information on abundance, seasonal occurrence, and ecology of key wildlife species or species-groups.

2. METHODS AND INFORMATION SOURCES

The report is primarily a review of existing information, but two field trips were made to the study area.

3. REGIONAL PERSPECTIVE

The entire Fraser Delta supports about 6,425 ha of vegetated wetlands, of which the foreshore marshes comprise 1,500 ha. Roberts Bank has about 700 ha of foreshore marsh, of which the Brunswick Point marshes make up 164 hectares. Most of the remaining marsh is along Westham and Reifel Islands. Up to 90,000 ducks, 20,000 snow geese and 50,000 shorebirds may winter in the delta area, including Boundary Bay. This is the largest population of wintering waterfowl in Canada.

4. WILDLIFE OCCURRENCE AND ABUNDANCE

Wildlife Habitats

Wildlife habitats in the vicinity of the pipeline route at Roberts Bank include the Foreshore Marshes, Canoe Pass, the Intertidal Sandflats, and the Delta Foreslope. The marshes are of most concern for wildlife, especially dabbling ducks, swans, and snow geese. The marsh habitat is subdivided into three vegetation zones, an upper riparian zone, a middle cattail-sedge zone, and a lower bulrush zone.

Wildlife Abundance

Snow geese and dabbling ducks are the key wildlife users of the Brunswick Point-Westham Island foreshore marshes. Brunswick Point is the single most important Fraser foreshore area for wintering snow geese and up to 5,000 may occur there at once. Most intensive use is from October to December, and feeding is almost entirely on bulrush rhizomes. Up to 10,000 dabbling ducks may occur at the Brunswick Point marsh (about 30% of Fraser foreshore total) and heaviest use is from September to December. Seeds of sedges and rushes are important dabbling duck foods in this area. Wintering geese and ducks may loaf on mudflats or open water seaward of the vegetated marshlands.

In summer, a few marsh wrens and blackbirds nest in the marshes, and many insectivorous birds feed over them. There is little waterfowl nesting or brood rearing in the foreshore habitats.

5. POTENTIAL IMPACT OF PIPELINE CONSTRUCTION

The Pipeline Project

The project is briefly described in terms of preferred route location, construction method, and construction timing and direction. Wildlife impact assessment is based upon landward construction along route B using the "bathtub" method. Dredging would take place from early June until the end of December, with a two-month contingency period (January and February). Construction through the Brunswick Point foreshore marsh would occur in November and December.

Wildlife Impacts

Impacts on wildlife could arise directly from disturbance as a result of construction noise and activity, or indirectly via habitat damage.

Direct disturbance is of considerable potential concern for dabbling ducks, swans, and snow geese which reach maximum abundance in this area during the proposed period of construction. However, this impact is predicted to be low because the route almost entirely avoids the marshland habitats of key importance for ducks and geese, and because Fraser Delta waterfowl are already conditioned to considerable human activity. Disturbance impacts could be more significant in the absence of strict control over support craft such as tugs, crew-boats, hovercraft and especially helicopters.

Habitat impacts are of greatest potential concern in the Brunswick Marsh segment of the proposed route, however, very little vegetated marshland would actually be excavated. The late fall construction period is favorable for temporary storage and replacement of the roots and rhizomes of marsh plants which are then dormant. In view of the small area involved and the anticipated revegetation program, this impact is of minor concern for wildlife.

Habitat restoration is considered to be more important than avoidance of direct disturbance of the birds. Because marsh revegetation is predicted to be more successful following late fall/early winter (landward) construction than following summer (seaward) construction, the landward schedule is preferred for wildlife if the route is to pass through a significant amount of vegetated marshland.

Wildlife impacts in Canoe Pass, the Intertidal Sandflats and Delta Foreslope primarily relate to disturbance or loss of benthic invertebrates eaten by diving ducks and some other birds. Since the zone of disturbance is small and the invertebrates are expected to recolonize dredged areas fairly quickly, this impact is considered to be negligible for wildlife.

6. MITIGATION MEASURES

Mitigation suggestions include control of the duration, location and extent of direct disturbances such as noise and vehicle movement, restriction of habitat damage to the smallest possible area, a marsh revegetation program (if and where needed), avoidance of wildlife habitats as sources of backfill, and protection against fuel spills.

If construction is carried out with care, and re-establishment of vegetation is successful, the pipeline project should have no residual impacts on wildlife.

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1. INTRODUCTION

1.1 Purpose of the Study

Estuaries are habitats of limited areal extent, but of key importance for fish and wildlife resources. Estuarine degredation in B.C. has been the subject of increasing concern and study in recent years, and the Fraser River delta has been at the forefront of this concern. One result has been the passage of Order-In-Council 908 by the Provincial Legislature, which requires that any proposed development project affecting Roberts Bank or other parts of the estuary be the subject of an environmental impact assessment. B.C. Hydro is considering extending its natural gas transmission/distribution system to Vancouver Island by underwater pipeline from the Lower Mainland, including a crossing of Roberts Bank. This report is intended to evaluate the impact of pipeline installation and operation on wildlife resources in that area.

This evaluation was carried out for British Columbia Hydro and Power Authority under Purchase Order 140 451 dated April 6, 1981. Client liaison was with Vancouver Island Gas Pipeline environmental study coordinator Mr. K.G. Farquharson. Terms of reference for the wildlife evaluation are included as Appendix 1. There was no significant departure from them.

1.2 Background Information

Considerable wildlife information is available for the Fraser Delta area, particularly seasonal inventory data for waterfowl, the most important species-group utilizing the foreshore marshes. Information on relative use of various parts of the delta, habitat selection, and food habits is available for the key waterfowl groups - dabbling ducks (Burgess 1970) and snow geese (Burton 1977). Several summaries of wildlife and habitat data for the Fraser estuary have been prepared in the past (Hoos and Packman 1974; Fraser River Estuary Study - Habitat Work Group 1978; Beak-Hinton 1977) and were useful reference documents. The existing information base is somewhat deficient with respect to wildlife inventory information for a very site specific development such as a pipeline, and in terms of knowledge of food chains or ecological pathways involving wildlife. However, these matters were considered to be known well enough in a general sense to allow a meaningful impact evaluation. The summer time frame of this study did not allow field observations to be made from autumn to spring - the critical period for wildlife use of the study area - however this is not considered to be a significant limitation in view of the generally good base of available data.

This report presents information on abundance, seasonal occurrence, and ecology of key wildlife species or species-groups. Knowledge of how the wildlife species utilize available habitats (habitat selection; food habits) is important for evaluation of indirect impacts, and has been presented where possible. However, the habitat itself has not been described in any detail in this report. The existing physical environment (climate; oceanography; substrates) has been described in a companion study by Monenco Consultants Ltd., and marine ecosystems (sediments; water quality; fish; invertebrates; marsh vegetation) by R.U. Kistritz Consultants Ltd. Human use of wildlife and other resources has been documented by Cypress Resource Consultants.

1.3 Acknowledgements

Thanks are extended to Gary Kaiser, Richard McKelvey, and Sean Boyd, Canadian Wildlife Service (CWS), Delta, for comments on avian use of the Roberts Bank area. Mr. Don Trethewey, also of CWS, kindly loaned some relevant reports. We also thank Ron Kistritz for providing useful habitat information and for commenting on an earlier draft of this report, and Kathleen Warren for providing background information on the pipeline project and useful editorial comment on this report.

2. METHODS AND INFORMATION SOURCES

This report is primarily a review of existing information. Little ecological information has been published specifically about Brunswick Point or the Southern Westham Island foreshore, hence most information is derived from more general reports on the Fraser River estuary. A list of relevant references is given in the Literature Cited section.

Reconnaissance field trips were made to the study area in May and July, 1981. Photographs taken and wildlife observations made during those surveys have been incorporated into the text. In addition, some information was gained by interviewing staff at offices of the Canadian Wildlife Service, Delta, B.C.

We reviewed draft reports by Monenco Consultants (August 1981) and Kistritz Consultants (February 1982) in order to assess wildlife impacts which might arise as a result of changes in the physical environment and/or estuarine ecosystem. Meetings with staff of those companies, B.C. Hydro, and Cypress Resource Consultants, aided our understanding of construction actions and alternatives which could directly or indirectly affect wildlife.

3. REGIONAL PERSPECTIVE

Roberts Bank wildlife habitats are an integral component of the total Fraser River estuary complex. Wildlife habitats and populations which could be affected at Roberts Bank should be seen in relation to total Fraser Delta habitats and populations. The following information is presented so that the later data on specific use of the Roberts Bank foreshore wetlands can be evaluated in such a context.

Forrester *et al* (1974) estimated that the Fraser estuary, including the foreshore from the North Arm to Mud Bay, and floodplains of the Fraser below Mission, the Pitt River below Pitt Lake, and Serpentine and Nicomekl Rivers, currently supports about 6,425 ha of vegetated wetlands. The foreshore marshes (exclusive of Boundary Bay) make up about 1,500 ha of this (Burgess 1970). Roberts Bank has about 700 ha of marsh, of which the Brunswick Point marshes make up 164 ha, and those along Westham and Reifel Islands comprise most of the remainder. Two plant communities dominate the foreshore marshes - an extensive outer zone dominated by bulrushes (*Scirpus americanus*) and an inner zone dominated by sedges, particularly *Carex lyngbyei*.

The region supports the largest population of wintering waterfowl in Canada, with forty species of ducks, geese, and swans present. About two million waterfowl from breeding grounds in eastern arctic USSR, Alaska, and western arctic Canada migrate along the Pacific Flyway, and at least one million pass through the Fraser Delta (Halladay and Harris 1972). Based on aerial surveys the ducks appear in late August, build to a peak of about 90,000 in November and December, decline through February to about 20,000, and reach a minor peak of about 35,000 again during spring migration in April. By May, most waterfowl have migrated north again. Very few stay to breed in the Fraser Delta area. About 15,000 snow geese (*Chen caerulescens*) winter in the Delta area.

Shorebirds are the second largest avian group using the delta foreshores (Taylor 1974), and at least 24 species occur. The wintering population has been estimated at 30,000 to 40,000 birds (Fry 1980), although flocks estimated in the hundreds of thousands may occur in spring. The Vancouver-Fraser Delta area has the second largest gull population on the west coast, with peak numbers of over 70,000 birds (Drent *et al*, 1971). Six species regularly occur. A few hundred great blue herons (*Ardea herodias*) utilize the area, and the only known rookeries are at Point Grey, Point Roberts, and east end of Boundary Bay. Raptorial birds are common in the area from fall through spring. Total populations are not known, but Vancouver Natural History Society counts resulted in 1,300 sightings from December 1970 to March 1972 (Taylor 1974). Passerine birds are abundant in the area, particularly during migration, but total numbers are not known.

4. WILDLIFE OCCURRENCE AND ABUNDANCE

In this section we are concerned with the Brunswick Point-Westham Island foreshore marshes (Figure 1) and adjacent parts of Canoe Pass and the outer sandflats.

4.1 Wildlife Habitats

Wildlife habitats in the vicinity of the proposed pipeline alignment may be classified as follows: (See also Table 1).

(1) Brunswick Point-Westham Island Marshes

These are the most important wildlife habitats in the vicinity of the proposed pipeline route across Roberts Bank. Soil conditions tend to be more silty than along outer parts of the route. The marshes exhibit slightly brackish conditions in winter, but their waters are fresh and of river origin during the rest of the year. Invertebrate biomass is relatively high in the marshes and adjacent mudflats, but species diversity is low. Polychaetes are the dominant benthic invertebrates, particularly in the outer part of this zone.

The Roberts Bank tidal marshes can be further subdivided as follows:

Riparian Zone adjacent to dykes

This consists of shrubby growth on the inside (east) of the dyke (Photo 1), and mixed grass-forb stands on the outside (west) of the dyke (foreground of Photo 2). Surficial materials are of fluvial origin and silt to sandy silt texture, drainage is poor, and tidal flooding is rare. This sub-zone is situated immediately above mean high tide, and is subject to some disturbance because it is the location of the storm strand line. Wildlife occurrence primarily involves songbirds, mice, and some fur-bearers such as muskrats and mink. This zone is more extensive in the Brunswick Point area than at Westham Island.

Cattail-Sedge Zone

This sub-zone lies seaward of the riparian zone. Dominant plant species are cattail (*Typha latifolia*) and Lyngby's sedge (*Carex lyngbyei*). Surficial materials are fluvio-marine in origin, of silt

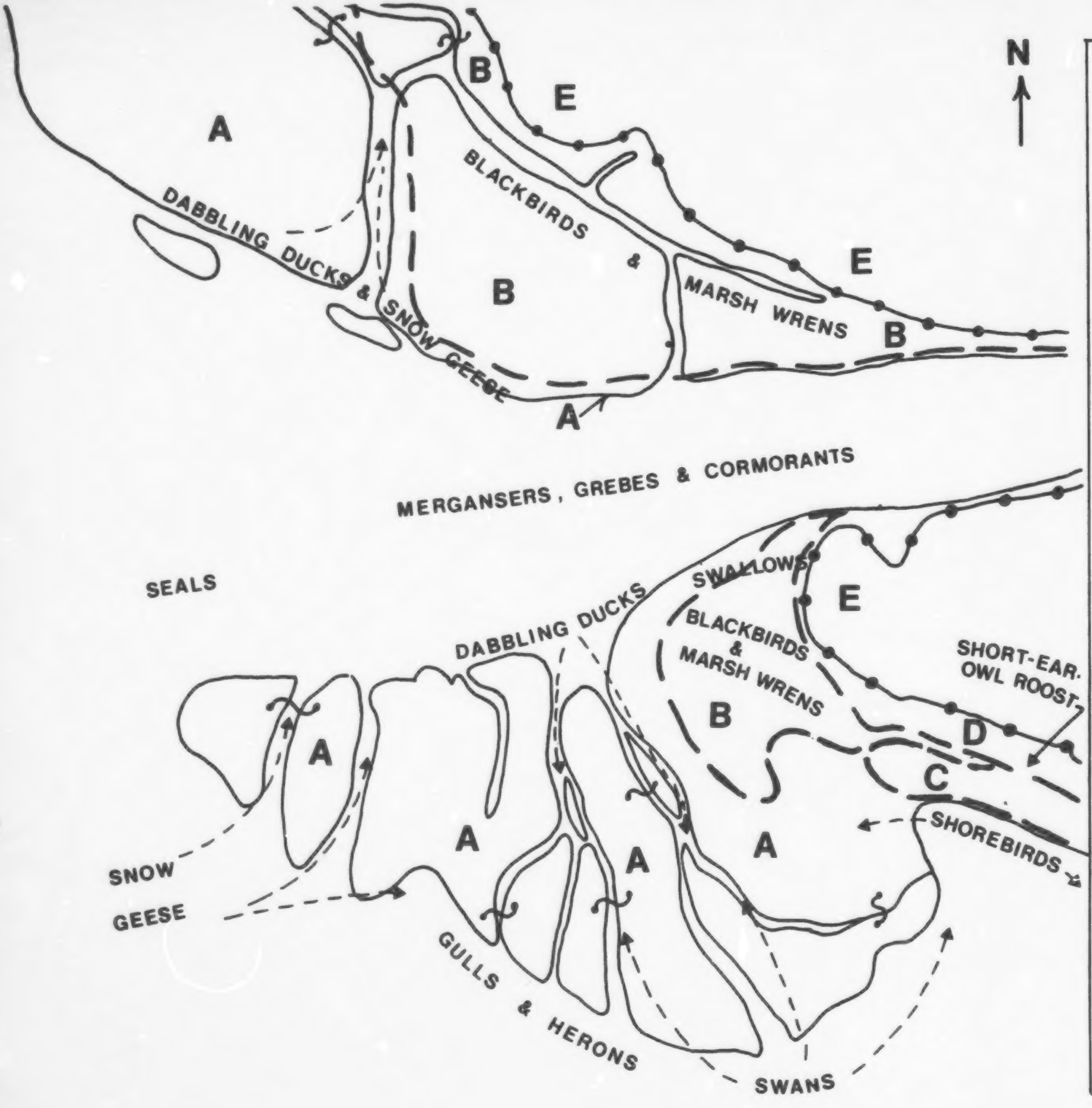
N
A
B
E
B
E
B
A
DABBLING DUCKS & SNOW GEESE
BLACKBIRDS & MARSH WRENS
MERGANSERS, GREBES & CORMORANTS
SEALS
DABBLING DUCKS
SWALLOWS
BLACKBIRDS & MARSH WRENS
E
B
SHORT-EAR. OWL ROOST
D
C
SHOREBIRDS
A
A
A
A
SNOW GEESE
GULLS & HERONS
SWANS

Figure 1. - Wildlife habitats and their use by key wildlife species, Brunswick Point and Southern Westham Island.

LEGEND

Dyke

Boundary between habitat types

Habitat Types

A . . . Bulrush zone
B . . . Sedge-cattail zone
C . . . Saltmarsh (*Triglochin-Distichlis-Salicornia*)
D . . . Grass-forb-shrub zone
E . . . Agricultural land

1 km

Table . - Major wildlife habitat types in Roberts Bank study area.[1]

Major Habitat Zones	Dominant Vegetation	Surficial Material	Material Texture	Drainage	Flooding Hazard	Generalized Habitat Capability				
						Waterbirds	Raptorial Birds	Songbirds	Aquatic Mammals	Land Mammals
Sand flats	Benthic algae (diatoms)	Marine	Sand	Underwater-Intertidal	Permanent-Daily	Low-Medium (w)				
Salt Marsh	Saltwort (*Salicornia virginica*) Arrowgrass (*Triglochin maritimum*) Saltgrass (*Distichlis stricta*)	Marine & Fluvio-Marine	Silt to Clayey Silt	Very poor	Frequent to Daily	Medium to High (w)	Medium-high	Low	Low	None
Bulrush Marsh	Softstem bulrush (*Scirpus validus*) Seacoast bulrush (*Scirpus paludosus*) Three-square bulrush (*Scirpus americanus*)	Fluvio-Marine	Silt to Clayey	Very poor	Frequent to Daily	High (g, s, w, sg)	High	Low	Low	None
Sedge/Cattail Marsh	Cattail (*Typha latifolia* Sedge (*Carex lyngbyei*)	Fluvio-Marine	Silt to Clayey Silt	Very poor	Frequent	High (g, w, da) I* (di)	High	Medium	Medium (m)	None-Low
Riparian Communities	Wet meadows Alluvial tree/shrub communities	Fluvial	Silt to Sandy	Poor	Frequent to Occasional	High (g, da)	High	High	High (m, b, o, mi)	Medium (r, sr)
Intensive Agricultural Lands	Vegetables, perennial pasture	Fluvial/ Organic	Silt, Sandy Silt, Fibrous	Poor to Imperfect		Medium-High (da, g, w)	High	Medium	Low-Medium	Medium (r, h, sr)

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[1] Adapted from Table 2 in "Fraser River Estuary Study: Habitat"

*I Indirect capability (i.e., zone plays a critical role in the food chain supporting these species).

Waterbirds: da = dabbling ducks, di = diving ducks; g = grazing waterfowl; s = swans; sg = snowgeese; w = wading birds.

Aquatic mammals: b = beaver; m = muskrat; mi = mink; o = otter; s = harbour seal

Land mammals: h = cottontail rabbit; r = raccoon; sr = small rodent.

to clayey silt texture, very poorly drained, and subject to frequent tidal innundation.

The cattail stands usually occur near the upper edge of this zone, in slight topographic depressions which contain standing water. They provide nesting habitat for blackbirds and marsh wrens, and occasional cover for pheasants.

The sedge stands at Brunswick Point grow from lower levels of 0 to 0.25 m up to 1.25 m geodetic (Kistritz 1982). Plant diversity in this sub-zone increases with elevation. Kistritz (*op cit*) noted sedge stem densities of about 650/m^2 in vigorous stands in the lower part of this sub-zone. Moody (1978) recorded an average peak aboveground standing crop of 909 gm/m^2 of *Carex lyngbyei* in the Fraser Delta foreshore marshes.

A variety of songbirds and dabbling ducks utilize this sub-zone.

Bulrush Zone

This is the most extensive foreshore vegetation type at Brunswick Point and Westham Island (Figure 1), and is located seaward from the Cattail-Sedge type. The dominant plant is three-square bulrush (*Scirpus americanus*). Surficial materials are fluvio-marine in origin, of silt to clayey silt texture, and subject to frequent to daily tidal flooding.

Kistritz (*op cit*) noted that the outer fringe of this sub-zone at Brunswick Point closely followed the -1.5 m geodetic contour which is 0.5 m below mean sea level. He determined the stem density of *S. americanus* to be 350 to 550/m^2. Moody (*op cit*) recorded an average peak aboveground standing crop of 397 gm/m^2 of *S. americanus* in the Fraser Delta foreshore marshes.

Dabbling ducks, snow geese, swans and shorebirds make extensive use of this sub-zone in the Brunswick Point and Westham Island marshes.

(2) Canoe Pass

This area is continuously flooded, but water depths, currents and salinity vary with tidal stage and Fraser River flows. Maximum depth (at scour holes) is about 6 m, and average depths are about 2 to 5 m.

Bottom materials are primarily sand. Canoe Pass waters are almost always quite turbid. Diversity of benthic invertebrates is high in this zone, but biomass is low. The inbenthos is dominated by amphipods and oligochaetes (Kistritz *op cit*). Seaward-moving juvenile fish are common in Canoe Pass in spring. This habitat zone is of relatively minor importance for wildlife, but is used by some piscivorous birds and by seals.

(3) Intertidal Sandflats

In the vicinity of the pipeline crossing, this extensive habitat type supports no vascular vegetation, but benthic algae may occur in the form of diatoms. Surficial materials are generally fine sand with less than 10% silt (Monenco 1981). Flooding and drying occur on a daily basis, but lower topographic situations are only exposed during very low tides. Diversity and abundance of benthic invertebrates are both generally low, particularly on the outer flats at elevations below +1.0 m. Most abundant invertebrates on the sandflats appear to be the bivalve *Macoma*, the amphipod *Eohaustorius washingtonianus*, and the polychaete *Paraonis platyuranchia*. This zone is relatively unimportant for wildlife, but receives some use by seals, shorebirds, and loafing waterfowl.

(4) Delta Foreslope

This subtidal area is located at the seaward edge of Roberts Bank. Water depth varies from about 5 to 20 m, and sediments are primarily sandy silt. Diversity and abundance of benthic invertebrates are both relatively high. Wildlife use here is limited to occasional passage of killer whales along the delta front, and benthic feeding by diving ducks in shallower parts of the foreslope.

4.2 Loons, Grebes and Cormorants

Abundance: Little work has been done on the use of the Fraser estuary by these groups of waterbirds, although incidental information on occurrence and distribution is available (e.g. Campbell *et al*, 1972).

Large numbers of Arctic loons (*Gavia arctica*) (up to 30,000 birds) and western grebes (*Aechmophorus occidentalis*) (up to 50,000) have been observed off Roberts Bank during spring migration (G. Kaiser pers. comm. in "Fraser

River Estuary Study - Habitat", 1978). These large groups probably feed on small fish in the foreslope area during spring. Canoe Pass is the only area in the immediate vicinity of Brunswick Point which is likely to receive much feeding activity from these groups. Double-crested cormorants (*Phalacrocorax auritus*) are known to gather along channels of the river mouth.

No loons, and only three western grebes were seen feeding in Canoe Pass during our field survey in May 1981 (Table 2). However, up to 54 cormorants were present, either feeding in the pass or loafing on logs or pilings along the south shore. G. Kaiser (pers. comm.) stated that larger numbers of western grebes had been present in the pass earlier in the spring. In July, one loon and two double-crested cormorants were seen in Canoe Pass. Eight cormorants were also seen loafing on a log off the southwest corner of the marsh.

Season of occurrence: This group occurs mostly as wintering birds, i.e. fall through spring. Some species, and particularly the double-crested cormorant, may be moderately abundant in Canoe Pass in response to fish runs, i.e. upstream movement of eulachons (*Thaleicthys pacificus*) and seaward migration of salmonid fry or smolts in spring.

Ecology: These groups are primarily fish feeders, occurring either in channels such as Canoe Pass, off the delta front, or over the sandflats when they are flooded. They have little direct dependence on the vegetated marshlands, and rarely occur in them.

4.3 Swans

Abundance: Campbell *et al* (1972) list both tundra (*Cygnus columbianus*) and trumpeter (*Cygnus buccinator*) swans as "rare winter" visitors in the Vancouver area. They state that wintering habitats of tundra swans include Brunswick Beach as well as other parts of the delta foreshore. Campbell *et al* (1974) recorded trumpeters from Pitt Meadows, Westham Island, Sturgeon Bank and Iona Island in 1972 but none from Brunswick Point or other parts of Roberts Bank.

However, R. McKelvey (pers. comm.) states that both species of swans are known to feed on the south side of Brunswick Point from December to March, where up to 150 have been counted. These appear to be approximately

Table 2. - Avian observations at Brunswick Point and Canoe Pass, May 7-8 and July 8 1981.

Species Group	May 7th and 8th		July 8th	
	Highest Count	No. Species Identified	Highest Count	No. Species Identified
Loons	-	-	1	-
Grebes	3	1	-	-
Cormorants	54	1	10	1
Herons/Bitterns	7	1	21+	2
Geese	5	1	8	1
Dabbling ducks	338	9	350+	5
Diving ducks	194	2	1	1
Coots	-	-	1	1
Shorebirds	50-100	2	11	3
Gulls	350	1	500-1000	2
Raptors	-	-	2-4	1
Songbirds	~ 150	13	~ 100	11
TOTAL	1151-1201	31	1005-1507	28

half tundra and half trumpeter swans. Smaller numbers also occur along the Westham Island foreshore. The number of trumpeter swans wintering in this area has been increasing in recent years, probably a result of the general population increase in this species reported by King and Conant (1981). The south edge of the Brunswick Point marsh is considered to be the most important trumpeter swan wintering habitat in the Fraser Delta.

The trumpeter swan is officially classified as a "rare" species by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). There is considerable concern for its' conservation, even though numbers appear to be currently increasing.

Season of occurrence: Seasonal use in this area has not yet been quantified by regular surveys, but is believed to be similar to other B.C. estuaries, i.e. about November 1 to late March or early April, with a peak during the coldest winter weather, usually January (McKelvey 1981).

Ecology: Most use of the Roberts Bank area by swans appears to be at the southern edge of the Brunswick Point marsh, but they also occur at Westham Island. According to G. Kaiser, the swans at Brunswick Point feed primarily on rhizomes of *Scirpus americanus*. Most of the feeding activity appears to be at the fringe of the marsh where bulrush growth is relatively sparse, however the swans do use the dense mat of marsh vegetation for roosting and shelter. At Comox B.C., McKelvey (1981) found the predominant foods of trumpeter swans, based on microscopic analysis of faeces, to be eelgrass (*Zostera* sp.) fronds (34% frequency), *Scirpus* rhizomes (31%), pasture grasses (19%), and *Carex* rhizomes (14%).

4.4 Snow Geese

Abundance: Burton (1977) did extensive research on use of the Fraser River estuary by snow geese and found them to be most numerous during spring and fall migrations. A population of up to 20,000 birds moves back and forth between the Fraser and Skagit River estuaries during winter. The first fall arrivals and last spring departures occur at Brunswick Point which Burton (*op cit*) attributed to "infections learning". Burton found a definite preference for Brunswick Point at population levels up to 5000 geese. Above this, Lulu Island (Sturgeon Bank) became more intensively utilized and the total population was split between the two areas. It was found that hunting pressures in the fall forced the geese to spend their days loafing at Reifel Refuge and during this time they showed a preference for Brunswick Point over Lulu Island for nocturnal feeding. As soon as hunting pressure was absent most geese restricted their movements to the two marshes and ignored Reifel Refuge.

Relative abundance and use of the Brunswick Point marshes by snow geese is shown in Table 3. The table shows that although Brunswick Point is the smallest marsh (13.7% of total area) it received 20.2% of goose use, 60% of which was comprised of feeding activity, giving it the highest importance rating. The high total use on Westham Island (51% of total) is due to hunting pressure and is comprised predominantly of birds resting in Reifel Refuge. Taylor (1974), using aerial survey data averaged over nine years (1966-1974), found a similar proportion of snow goose occurrence to be along the Brunswick foreshore.

No snow geese were seen at Brunswick Point during our surveys in May and July, 1981, although a few were present at Reifel Refuge in May.

Season of occurrence: First arrivals are in October, last departures in April.

Ecology: The attraction to the Brunswick Marsh area is at least partly due to the presence of dense stands of *Scirpus americanus* and *Scirpus paludosus* occurring along the western portions of the marsh. Burton (1977) found that the geese fed almost entirely on the rhizomes of those two bulrushes. Lulu and Sea Island foreshores appeared at least as suitable for feeding activity with respect to rhizome densities and yet he found that the geese were not using those areas at all in November and December. He concluded that "Brunswick Point is clearly the most important single marsh per unit area and may be assumed critical to the continued survival of snow geese in this area."

4.5 Other Geese

Canada geese (*Branta canadensis*) are primarily grazers and forage mostly in agricultural areas, therefore relatively little use is made of the Roberts Bank foreshore marshes. However, large numbers of these geese winter on Westham and Reifel Islands and some also nest there (Dawe and Davies 1976), therefore some use of the adjacent tidal marshes is likely. Five

Table 3. - The feeding intensity, use intensity, and relative importance of Fraser Delta marsh units for wintering snow geese (from Burton 1977).

Location	Use Intensity (1000 goose days) a	Mean Feeding Intensity (%)* b	Marsh Size (100 ha) c	Index Importance** d
Brunswick Marsh	149.9	0.60	1.34	67.1
Westham Island Marsh	379.3	0.15	3.50	16.3
Lulu Island Foreshore	169.9	0.51	3.54	24.5
Sea Island Foreshore	44.9	0.38	1.43	12.0
Total	744.0		9.81	

* % of time spent feeding, expressed as a decimal fraction

** $d = \frac{a}{c} \times b$

Canada geese were seen loafing on the north shore of Canoe Pass during our field trip on May 7th and a pair flew over the marsh the following day. Eight were seen along the southwest shore of the marsh in July.

Large numbers of brant (*Branta bernicia*) migrate northward through the Fraser Estuary area every spring (Hoos and Packman, 1974). A few hundred migrate southward along this route in fall and a few small flocks stay for the winter. (Fraser River Estuary Study-Habitat 1978). Most of these birds congregate at the large eel-grass (*Zostera marina*) beds in Boundary Bay and lesser numbers occur between the Coal Port and Ferry Terminal jetties on southern Roberts Bank. No eel-grass beds exist in the immediate vicinity of Brunswick Point or Westham Island and this area is not expected to be used by these birds.

Small numbers of white-fronted geese (*Anser albifrons*) winter on Westham Island and spring migrants usually pass through in early May (Campbell *et al* 1972). Use of the Brunswick Point-Westham Island area is expected to be slight. None were seen during our field trips though Campbell *et al* (1972) list three seen in Canoe Pass on May 10th, 1970.

4.6 Dabbling (Surface-feeding) Ducks

Abundance: Burgess (1970) recorded a high count of 15,000 dabblers at Brunswick Point, although average counts (Table 4) are considerably lower. His highest count at Westham Island was about 12,000, however the larger series of counts summarized by Taylor (1974) indicate monthly average counts there as high as 20,000 birds (Table 4). Average monthly counts for all of Roberts bank have peaked at about 30,000.

Dabbling ducks on the Brunswick-Tsawwassen foreshore comprised up to 31% of the Fraser foreshore total; on the Westham Island foreshore the highest proportion was 53%. Roberts Bank monthly averages varied from 34 to 76% of the Fraser foreshore totals (Table 4).

While mean monthly counts have generally been higher at Westham Island than Brunswick, the latter area has a much smaller amount of vegetated marshland, and probably supported more dabbling duck use per unit area than did Westham Island. It is apparent that either area, and the total Roberts Bank foreshore, can support a high proportion of total dabbling duck use on the Fraser foreshore.

Table 4. - Abundance of dabbling ducks at Brunswick Point and Westham Island, relative to abundance on the entire Fraser Delta foreshore.

Month	Mean counts of dabbling ducks, 1966 to 1974[1]			
	Brunswick/ Tsawassen	Westham Island	Total Roberts Bank	Total Fraser Foreshore[2]
Sept.	8,632 (30)*	2,437 (9)	11,069 (39)	28,735
Oct.	9,093 (31)	7,036 (24)	16,129 (55)	29,029
Nov.	8,899 (22)	20,505 (51)	29,404 (73)	40,512
Dec.	9,788 (27)	17,341 (49)	27,129 (76)	35,780
Jan.	3,346 (18)	10,062 (53)	13,408 (71)	18,847
Feb.	1,963 (20)	2,872 (29)	4,835 (49)	9,766
Mar.	157 (1)	5,748 (47)	5,905 (48)	12,255
Apr.	1,044 (7)	3,786 (27)	4,830 (34)	14,049
May	317 (6)	1,634 (28)	1,951 (34)	5,815
Total	43,239 (22)	71,421 (37)	114,660 (59)	194,788

[1] Data from Taylor (1974:18) except for May, which was calculated from Burgess (1970:111)

[2] Includes Sturgeon and Roberts Banks, but not Boundary Bay-Mud Bay

* Figures in parantheses are percentages of the Total Fraser Foreshore counts.

A small number of dabbling ducks nest in the Roberts Bank area, however, the tidal marshes are generally not important as production habitat.

Our field survey in May 1981 found 300-350 dabblers using the Brunswick marshes (Table 2). Virtually all use was concentrated around the north end of the large north-south channel that dissects the marsh, though the occasional bird was flushed from ponds east of that channel. Most birds seen were American wigeons. In all, nine species were observed. These are listed below followed by their highest count during the surveys: American wigeon (*Anas americana*) 250; green-winged teal (*Anas crecca*) 30; pintail (*Anas acuta*) 20; northern shoveler (*Anas clypeata*) 11; mallard (*Anas platyrhynchos*) 10; gadwall (*Anas strepera*) 10; cinnamon teal (*Anas cyanoptera*) 4; blue-winged teal (*Anas discors*) 2; and European wigeon (*Anas penelope*) 1. In July, most dabblers were again in that channel, but concentrated further south where it divides into two. At least 350 birds were flushed here (including a few broods) and although some mallards, gadwall, wigeon and green-winged teal were observed, the majority were not identified. As in May, occasional mallards, gadwall and blue-winged teal were flushed from small channels and ponds between the large north-south channel and the dyke. Most of these were lone females.

Species Composition: Burgess (1970) found American wigeon, green-winged teal, pintail and mallard to be the most common species in the Brunswick Marsh area, accounting for 41.2%, 36.4%, 12.9% and 9.5% respectively of all observations. At Westham Island, those species accounted for 30.7, 20.9, 18.3, and 30.1% respectively of cummulative dabbler counts.

Season of occurrence: Dabbling ducks may be present in relatively large numbers in the tidal marshes from the last week in August until the first week in May. Peak abundance for the Fraser foreshore appears to be in November, but numbers are also high in October and December (Taylor 1974, Figure 5). Fall and early winter use is definitely greater than late winter-early spring use.

In the Brunswick-Tsawwassen area, average counts were highest and relatively constant from September through December, and then declined considerably. At Westham Island, they rose from relatively small numbers in September to a peak in November, then declined steadily to February and remained quite low thereafter (Table 4).

Ecology: On the Roberts Bank foreshore, dabbling ducks loaf on open water beyond the vegetated marshland, and feed in shallow waters in and adjacent to the marshes, including narrow channels and ponds. Feeding locations vary with stage of tide. These ducks also make feeding flights to agricultural lands, therefore all of their feeding is not done in the tidal marshes. Burgess (1970:89) noted that in September most ducks are in the tidal marsh area, food availability is at its peak because plants are just releasing their seeds, and feeding on the tidal marsh is extensive. In October a larger proportion of the ducks is loafing on non-tidal portions of the foreshore, food availability on the tidal marshes during daylight hours is greatly reduced because of tidal flooding, and tidal marsh feeding is greatly reduced. From late October to early January the majority of ducks loaf on open water, off-shore from the tidal marshes, and food availability on the tidal marsh remains low as daytime tides become higher for longer periods. Limited feeding on the tidal marsh is restricted to optimum tide levels, and most feeding involves flights to flooded farmland by day or night. From mid January to March an increasing proportion of the wintering population begins to appear on the tidal marsh as food availability improves with decreased daytime tide levels. By April most of the few remaining ducks are present on the tidal marshes and feeding there is common during low daytime tides.

Food habits studies by Burgess (1970) showed that tidal marsh plant material, primarily seeds of *Carex lyngbyei, Scirpus americanus*, S. *validus*, and *Eleocharis macrostachya*, made up about 75% of mallard food, 65% of pintail food and 50% of green-winged teal food in the Fraser Delta area in winter. The remainder of the diet was mostly obtained from agricultural lands. Wigeon, which prefer to eat green vegetation, obtained the bulk of their food from farm fields, but spent much time resting on the foreshore.

4.7 Diving Ducks

Abundance: Numbers of diving ducks using the Brunswick Point/Westham Island foreshore have not been determined. Over an entire year, Blood (1978) determined that dabbling ducks were 7.5 times more abundant than diving ducks in the South Arm of the Fraser River, and adjacent areas. Vermeer and Levings (1977) reported the occurrence of up to 400 diving ducks at Sturgeon and Roberts Banks in summer. Winter numbers should be considerably higher than that, but much less than those of dabbling ducks.

Only two species of diving ducks were observed during our May, 1981 survey. Red-breasted mergansers (*Mergus serrator*) were common at high tide (high count of 192) in Canoe Pass and in and around the mouth of the large channel that dissects Brunswick Marsh. In addition, a pair of bufflehead (*Bucephala albeola*) was seen in that channel at low tide on May 8th. In July the red-breasted mergansers were no longer present and the only diver seen was a common merganser (*Mergus merganser*) among a large group of dabblers in the same channel.

Species Composition: Vermeer and Levings (1977) indicate that surf scoters (*Melanitta perspicillata*) and greater scaup (*Aythya marila*) are the most abundant divers of the entire Fraser Delta intertidal areas, including Boundary and Mud Bays. Blood (1978) reported that scaup, bufflehead, goldeneye and scoters (in that order) were the most abundant species in the South Arm of the Fraser River. Campbell *et al* (1974) list surf scoter and greater scaup as "abundant"; common and Barrow's goldeneye (*Bucephala clangula* and B. *islandica*), bufflehead and red-breasted merganser as "common" and canvasback (*Aythya valisneria*), lesser scaup (A. *affinis*), oldsquaw (*Clangula hyemalis*), harlequin (H. *histrionicus*), white-winged and black scoter (*Melanitta deglandi* and *Oidemia nigra*), ruddy duck (*Oxyura jamaicensis*) and common merganser as "fairly common" in the Vancouver area, including the Fraser Delta, in winter.

Season of occurrence: Greatest occurrence is from fall to spring.

Ecology: Most of these species feed in fairly deep water over unvegetated substrates. They are unlikely to be common at Brunswick Marsh or Westham Island, but probably make sporadic use of Canoe Pass, and of the sandflats and foreslope when tidal conditions are suitable. Scaup and bufflehead frequently occur in the more inshore area, including tidal flat channels and therefore are more likely to use the foreshore marshes. Mergansers, like other fish-eating species, are likely to occur in Canoe Pass in conjunction with fish runs.

Of six diving duck species investigated by Vermeer and Levings (1977), black, surf and white-winged scoters and oldsquaws fed primarily on bivalves; common goldeneyes on crustaceans; and greater scaup on vascular plants and algae. Most abundant bivalves in diving duck diets were *Mytilus edulis*, *Mya arenaria*, *Clinocardium nuttallii*, and *Protothaca staminea*. Most common crustaceans were *Balanus glandula*, *Cancer productus*, *Telmessus cheiragonus*, *Upogebia pugettensis*, *Crangon franciscorum*, *Atylus* sp., and *Idotea* sp. Snails were moderately important in the diet of white-winged scoters and scaup.

4.8 Shorebirds

Abundance: Shorebirds are the second most abundant group of birds utilizing the foreshores of the Fraser Delta. The total number which migrates through the Fraser Delta area is not known, but several hundred thousand may be present at the peak of spring migration (G. Kaiser, personal communication) and over 100,000 in the fall (Fry 1980). Those birds make considerable use of Boundary Bay as well as the foreshore. Sverre (1974) estimated that 40% of Fraser Delta shorebirds use the Boundary Bay foreshore, 35% use Sturgeon Bank and 20% use Roberts Bank. Drent *et al* (1971) showed that although Boundary Bay supported over 60% of dunlin activity, Roberts Bank was second (22%) and Sturgeon Bank third (10%).

The major wintering species is the dunlin (*Calidris alpina*), which may also be abundant in migration. For the Roberts Bank-Boundary Bay area, Fry (*op cit*) found that dunlin numbers peaked in early November at about 110,000 birds, and that the winter population was about 25,000 to 40,000. During spring migration, about 60,000 dunlins were present in the highest count. Counts from Boundary Bay were consistently higher than those from Roberts Bank, the latter reaching only 38,000 compared to 109,250 for the former.

The most important part of the Roberts Bank foreshore for shorebirds appears to be the reach from the south edge of the Brunswick Point marsh to the Tsawwassen Ferry causeway.

During our field trip in May, shorebird use of the Brunswick Point area was quite low. A few flocks of up to 25 "peeps" (small sandpipers of the genus *Calidris*) were noted flying over the marsh. Small groups (1-6) of least sandpipers (C. *minutilla*) were frequently seen feeding among the bulrushes and a pair of killdeers (*Charadrius vociferous*) was seen at the dyke.

In July, even fewer shorebirds were observed. A pair of killdeers and three "peeps" were flushed from damp muddy areas between the dyke and the north-south channel which dissects the marsh. Eight "peeps" were seen foraging at the mouth of that channel and two dowitchers (*Limnodromus* sp.) and one killdeer were flushed further south along it.

Species composition: Campbell *et al* (1972) list at least 30 species occurring in the area, the most common being the dunlin, semipalmated sandpiper (*Calidris pusillus*) and western sandpiper (C. *mauri*).

Season of occurrence: Almost all shorebird use of the Fraser Delta is by migrating or wintering birds which nest in the Arctic. However, the season of use may be long, since "fall" migrants begin returning in July, and the latest spring migrants pass through in May. Because the spring migration is compressed into a short period of time, numbers are highest at that time, and the peak of spring migration is about the first week in May. However, there are species variations, the spring peak in dunlin abundance, based on maximum daily counts, being about April 10-11 (Fry *op cit*). While the fall migration of shorebirds generally occurs over an extended period, dunlins showed a pronounced peak in early November.

Ecology: Dunlins wintering at Roberts Bank appear to be part of a coherent population which used Roberts Bank at low tides and Boundary Bay at higher tides. Maximum numbers at Roberts Bank were recorded at low tides, with Boundary Bay being the high tide roost of most flocks. These birds move back and forth across the Point Roberts Peninsula. According to Fry (*op cit*), dunlins at Roberts Bank "... were seen in greatest numbers just south of the Brunswick Point marsh, although flocks moved southward as tide levels rose, and flocks were regularly seen foraging adjacent to the coalport causeway. The area between the two causeways was used most regularly as the point of arrival from and departure to Boundary Bay." Roberts Bank dunlins also make some use of farm fields.

Shorebirds feed mostly on small invertebrates which they obtain by probing into the mud, or pick up on the mud surface or in shallow water. In the case of dunlins, Fry (*op cit*) noted a preference for polychaete worms, particularly *Nereis limnicola*, small burrowing amphipods and juvenile gastropods and molluscs.

4.9 Gulls

Abundance: About 70,000 gulls winter in the Vancouver-Fraser Delta area (Drent *et al*) but the Brunswick Point-Westham Island area appears to be of little significance. It is not one of the major Lower Mainland roosting or feeding sites mapped by Campbell *et al* (1972:154). A few hundred birds may feed in the area at any time of the year. The nearest nesting area is the Tsawassen Ferry Terminal.

Our May, 1981 survey found gulls most common at Brunswick Marsh at high tide when about 350 were recorded feeding and flying around, mostly on the western half of the marsh. All those identified were glaucous-winged gulls (*Larus glaucescens*). In July, gulls were again most common at high tide, but were concentrated along the southwest shore of the marsh, and a few were constantly flying overhead. A Caspian tern (*Hydroprogne caspia*) was also seen foraging over and around the marsh.

Species composition: Wintering gulls in the Fraser Delta area consist mainly of glaucous-winged gulls (65,000-70,000) and mew gulls (*Larus canus*) (5,000-8,000) (Drent *et al*, 1971). Other species regularly visiting the delta include herring (L. *argentatus*), Thayer's (L. *thayeri*), California (L. *californicus*) and Bonaparte (L. *philadelphia*) gulls. Campbell *et al* (1972) list an additional ten species of gulls and terns which have been recorded in the area.

Ecology: Most gulls scavenge at garbage dumps and other sites where man provides food, however some do forage on natural food items in intertidal areas.

4.10 Marsh Birds

Great blue herons (*Ardea herodias*) are the most common marsh bird in the area, however only small numbers utilize the Roberts Bank foreshore, possibly because of its distance from nesting sites. Surveys from Iona

Island to Mud Bay between May 1973 and January 1974 (Sverre 1974) revealed that only 3% of heron sightings were on the Roberts Bank foreshore. Up to seven herons were seen foraging the shores of the marsh during our survey in May, 1981. They concentrated along the large north-south channel at lower tides and were more common along the northeast shore at higher tides. They were much more common in July when over twenty were seen, most along the southwest shore but also along the tidal channels and other shorelines. Other marsh birds noted include one American bittern (*Botaurus lentiginosus*) and one American coot (*Fulica americana*), both recorded in July.

4.11 Raptorial birds

Due to their position at the top of the food chain, raptors are less abundant than most other avian groups. However they are important because of their great interest to naturalists and the rare or endangered status of some species. Twenty-one species have been recorded in the Fraser Delta of which bald eagles (*Haliaeetus leucocephalus*), red-tailed hawks (*Buteo jamaicensis*), marsh hawks (*Circus cyaneus*), short-eared owls (*Asio flameus*) and peregrine falcons (*Falco peregrinus*) are the major users of estuarine habitat (Fraser River Estuary Study-Habitat, 1978). Fry (1980) also observed rough-legged hawks (*Buteo lagopus*), merlins (*Falco columbarius*), turkey vultures (*Cathartes aura*), and snowy owls (*Nyctea scandiaca*) on the foreshore.

Sverre (1974) found 72% of foreshore use by raptors to be on Sturgeon Bank, with most of the remainder at Westham Island and Boundary Bay. Taylor (1974) summarized Vancouver Natural History Society raptor counts in the Fraser Delta, and found Westham Island to be the most intensively used area.

Most raptor occurrence in this area is from November to March. Fry (*op cit*) noted that numbers peaked in early January. We saw no raptorial birds in the area during surveys in May 1981, but two or more marsh hawks were observed in July.

Most use of the foreshores by raptors involves hunting for food, mostly avian prey or carion. Fry (*op cit*) saw merlins regularly at the base of the Coalport Causway, and twice observed this species with dunlin kills. Peregrines were seen at the same location, and unidentified falcons were observed chasing dunlins. Fry noted that bald eagles were seen from January onward, sitting on tidal flats with duck kills, as were red-tailed hawks, and that snowy owls often roosted on prominent perches in the Brunswick Point marsh. Short-eared owls are also known to roost in the grass-shrub zone just outside the dyke at Brunswick Point (Canadian Wildlife Service staff, personal communication). There is little such habitat at Westham Island, where high tides come to the base of the dyke, and therefore this phenomenon is not expected to occur there.

4.12 Upland gamebirds

Ring-necked pheasants (*Phasianus colchicus*) are common in shrubby habitat and on agricultural fields on the delta. Cattail and bulrush marshes are important cover areas during hunting season (Fraser River Estuary Study-Habitat, 1978), therefore the inner part of the Brunswick Point marsh is probably used by pheasants. None were seen on the Brunswick Point marshes in May or July, 1981, however one was flushed from marsh vegetation beside the Coal Port Jetty on May 8th.

4.13 Songbirds

Typical passerines using foreshore habitat include swallows, crows (*Corvus brachyrhynchos*), marsh wrens (*Cistothorus palustris*), robins (*Turdus migratorius*), starlings (*Sturna vulgaris*), blackbirds (*Agelaius phoeniceus* and *Euphagus* sp.) and song sparrows (*Melospiza melodia*). Most of these species utilize dense marsh vegetation, particularly in the upper zone which is little flooded. Swallows and other insectivorous species make regular feeding flights over the wetlands.

Our May, 1981 survey found barn swallows (*Hirundo rustica*) to be the most abundant passerine in the area, due mostly to the availability of nesting sites in the adjacent old cannery buildings. They were constantly seen foraging over the marsh and were occasionally joined by one or two cliff (*Petrochelidon pyrrhonota*) and tree (*Tachycineta bicolor*) swallows. Red-winged blackbirds (A. *phoeniceus*) and robins were also common at the marsh, along with some Brewer's blackbirds (*Euphagus cyanocephalus*), savannah sparrows (*Passerculus sandwichensis*) and crows. Other species seen around the dyke shrubbery and the old cannery in May include golden and white-crowned sparrows (*Zonotrichia* spp.), starlings, American goldfinches (*Carduelis tristis*) and song sparrows.

In July, barn swallows were still abundant and, along with lesser numbers of cliff and tree swallows, were usually seen foraging over the marsh between the dyke and the outer channels. Red-winged blackbirds and marsh wrens were common in and around cattail stands and many young blackbirds were already fledged. A few American goldfinches, house finches (*Carpodacus mexicanus*), robins, savannah sparrows, crows and Brewer's blackbirds were also seen.

4.14 Mammals

A large number of mammal species occur in the Fraser Delta area, but a much smaller number is of importance at Brunswick Point and adjacent parts of Roberts Bank. A few mice, muskrats (*Ondatra zibethica*) and mink (*Mustela vison*) undoubtedly occur in the upper foreshore near the dykes, but are of little economic importance. Harbour seals (*Phoca vitulina*) occur in adjacent offshore waters and channels and a haul-out site occurs on a bar northwest of Brunswick Point in the mouth of Canoe Pass (Fraser River Estuary Study-Habitat, 1978). These animals are wary and will not tolerate persistent human activity nearby. They need daily haul-out areas in undisturbed localities and favour sandbars with access to deep water channels. Of 730 seals recorded during a photographic census of the Fraser estuary in August 1976, 165 (23%) occurred on Roberts Bank, all of which were hauled out at four sites northwest of Brunswick Point. Use of the haul-out areas is primarily from June through August.

Up to three seals were commonly observed in Canoe Pass from the old cannery wharf during our surveys in May, 1981. The only other mammals seen in the vicinity were a Norway rat (*Rattus norvegicus*) at a wood pile beside some cannery buildings, and four rabbits (*Sylvilagus floridanus*). Two rabbits were seen in dense shrubbery behind the dyke, one was beside the Coal Port Jetty road, and one was seen beside the gravel road at the east end of the cannery.

4.15 Summary of wildlife occurrence

The approximate maximum abundance of key wildlife species or species groups in the Brunswick Point-Southern Westham Island area is summarized in Table 5. The habitat types of greatest importance for each species, and the season or seasons of greatest use, are also listed.

Table 5. - Summary of wildlife use of the Fraser River foreshore at Brunswick Point and southern Westham Island.

Species/Group	Approx. Abundance on Brunswick Point-Southern Westham Island Foreshore	Major Habitat Type of Importance	Season of Use
Piscivorous birds (Loons; grebes; cormorants)	Up to 500	River channels and flooded sandflats.	Mostly spring (fish runs).
Herons	< 50	Shallow channels and shorelines.	Year-round; probably peak in fall.
Swans	Up to 150	Edges of bulrush zone.	November-March.
Snow geese	5,000-10,000	Vegetated marshland partic. *Scirpus* zone.	Winter (Oct. through April).
Dabbling ducks	Up to 20,000 in fall (usually 8,000-10,000)	Vegetated marshland; small ponds and channels.	Mostly fall and winter; some present year-round.
Raptors	10-50	Dykes, marshland, sandflats, and adjacent waters.	Mostly late fall and winter.
Shorebirds	Up to 40,000	Channels, shorelines and sandflats exposed at low tide.	Peak in spring and fall; abundant in winter.
Gulls	Up to 500	Shorelines and sandflats.	Mostly winter; present year-round.
Passerines	< 1,000	Upper marsh zone (cattail-sedge); also dyke area.	Summer (nesting; feeding).
Seals	Up to 200	Sandbars exposed at low tide at edge of Canoe Pass.	Summer (haul-outs; pupping).

5. POTENTIAL IMPACT OF PIPELINE CONSTRUCTION

5.1 The Pipeline Project

Design considerations such as pipeline route selection, construction methods, construction timing, and direction (landward or seaward) have been based upon a variety of environmental, engineering and economic factors. Wildlife information was made available to project staff who made decisions or recommendations on those matters. The following discussion of potential impacts on wildlife resources is based on project description information available to us in late 1981. The discussion of project impacts largely involves those impacts which are unavoidable.

5.1.1 Route location

In this report we are evaluating the wildlife impacts of pipeline installation along Route B shown in Figure 2. The location of the route across Roberts Bank was largely determined by the path chosen for descent of the delta foreslope, the crossing of the dyke in relation to the Brunswick Point marshes, migration of the Canoe Pass channel, and the presence of the buried electrical cables south of Brunswick Point.

We feel that Route B is a suitable choice because it would cross little or none of the Roberts Bank foreshore marsh.

5.1.2 Construction Method

Evaluation of wildlife impacts is based upon the "bathtub" method of construction. Wildlife implications of other techniques such as trench and pull, deep ploughing or jetting were not assessed. The depth of burial required for crossing Roberts Bank, to allow for lateral wandering of Canoe Pass Channel, is 5 to 7 meters. Because it would be impossible to keep any significant length of trench open to this depth it is proposed to use the "bathtub" technique wherein only a short length of trench is kept open to allow placement of the pipelines while the construction train moves across the Banks. Twin 12 or 16 inch pipelines will be laid across Roberts Bank in a common trench except at the head of the foreslope where they would be separated as they descend the foreslope. A right-of-way 120 m wide

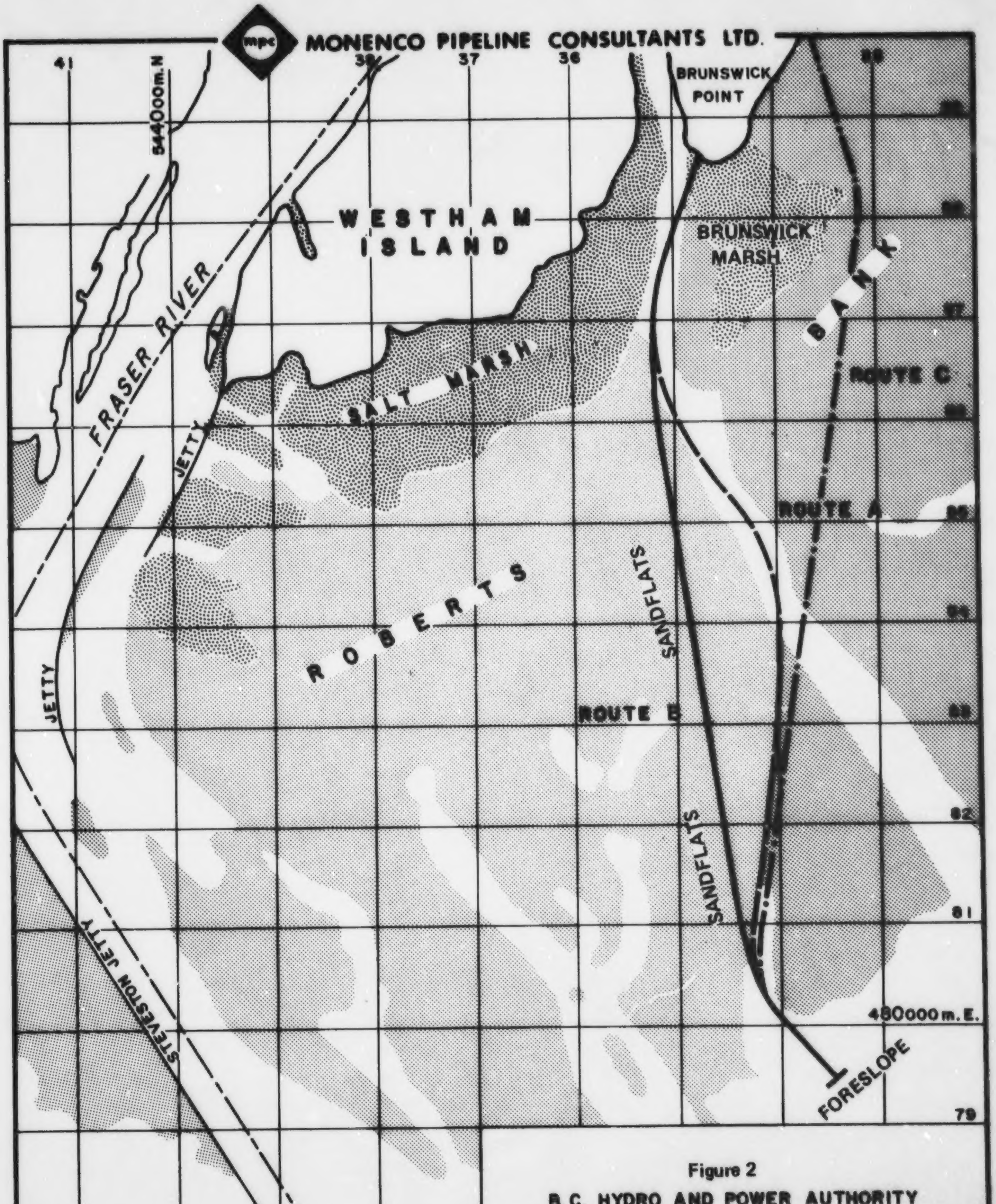
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Figure 2

B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT
ALTERNATIVE PIPELINE
ROUTES ACROSS ROBERTS BANK

is required from Brunswick Point to the point of pipeline divergence near the foreslope where the right-of-way would start a tapered transition to a maximum width of 300 m, where the pipelines are 150 m apart.

The bathtub construction method is summarized below so that the reader of this report can more readily understand its potential impact on wildlife and wildlife habitat. For more detail on construction methods the reader is referred to Monenco (1981) and B.C. Hydro (1982).

The first unit in the construction train is a floating suction dredge which pumps the excavated material through a flexible pipe to the third unit in the train, a backfill unit from which deposition of dredgeate is controlled. The shallow-water laybarge floats in the dredged trench between the dredge and backfill units. Pipes are welded on the laybarge and slid into the trench as the laybarge is winched forward using anchors that are placed on the banks. The construction train would move steadily, with the three vessels floating in a "bathtub" when the banks are exposed at low tide. Two pipelines would be laid simultaneously and the dredgeate deposited directly in the trench. Rate of advance would be controlled by dredging capacity. Maximum length of the "bathtub" would be 400 m and its width is expected to be 50 to 60 m, depending on local soil characteristics. Due to loss of fine material, the "bathtub" would become longer as the train advanced. Assuming a landward construction sequence, the dredge would stop excavating when it reached the south edge of Canoe Pass and would move downstream to sand banks to obtain material necessary to fill the last section of trench. The trench excavated from Canoe Pass toward the dyke would be completed using land based equipment such as draglines, clamshells, and excavators. If this section of the work was through the tidal marsh it would be preceded by removal and storage of enough marsh vegetation to permit effective restoration of the marsh following backfill of the trench. A potential restoration program is described in B.C. Hydro (1982). Construction through the dyke would involve the use of a cofferdam on the seaward side of the dyke to protect the breach in the dyke. The dredge and backfill unit would work on a 3 shift, 24 hour day, 7 day week basis, while the laybarge crews would work a single shift, 7 days a week. Crews would be transported by workboat, hovercraft or helicopter depending on weather and tide conditions and laybarge location. The base for workboat operations would probably be Canoe Pass. Delivery of pipe and materials to the laybarge would be by shallow draft barges and tugs, or landing craft, which would cross the banks into the "bathtub" at high tide. Prior to connection to the land pipeline, the Roberts Bank segment would be hydrostatically tested. Test water would be discharged at the seaward end, and would contain rust and some corrosion inhibitor.

5.1.3 Construction Timing and Direction

Because the dredging program requires less than a year (6½ to 7 months) and will proceed temporaly across the bank, there is some opportunity to avoid critical environmental events by appropriate timing. Avoidance of construction activity in a particular place at a particular time can be achieved by varying the date of initiation of construction and the direction in which construction proceeds. Major factors of concern relative to the construction schedule (not necessarily in order of importance) were as follows:

a). avoid juvenile salmonids in the Canoe Pass-Brunswick Marsh area in spring,

b). avoid blockage of upstream salmon movement in Canoe Pass in summer and fall,

c). avoid soft shell life history phase of edible crabs in the sandflat/foreslope area (May-June),

d). avoid dredging through Brunswick Marsh during the summer growth phase of marsh plants (dormant period preferred),

e). avoid blockage of Canoe Pass during periods of high boat traffic,

f). avoid construction on the outer, exposed part of Roberts Bank during the bad weather season (late fall and winter),

g). avoid disturbance of ducks and snow geese which feed at Brunswick Marsh from fall to early spring,

h). avoid interference with fall-early winter hunting activity at Brunswick Marsh.

The landward construction sequence, with dredging beginning in mid-June at the foreslope and finishing in Brunswick Marsh at the end of December, was deemed to have the most advantages and was adopted as the basis for environmental impact evaluation. The proposed dredging/backfilling components of the landward schedule are shown in Figure 3. Dredging is preceded and followed by periods of

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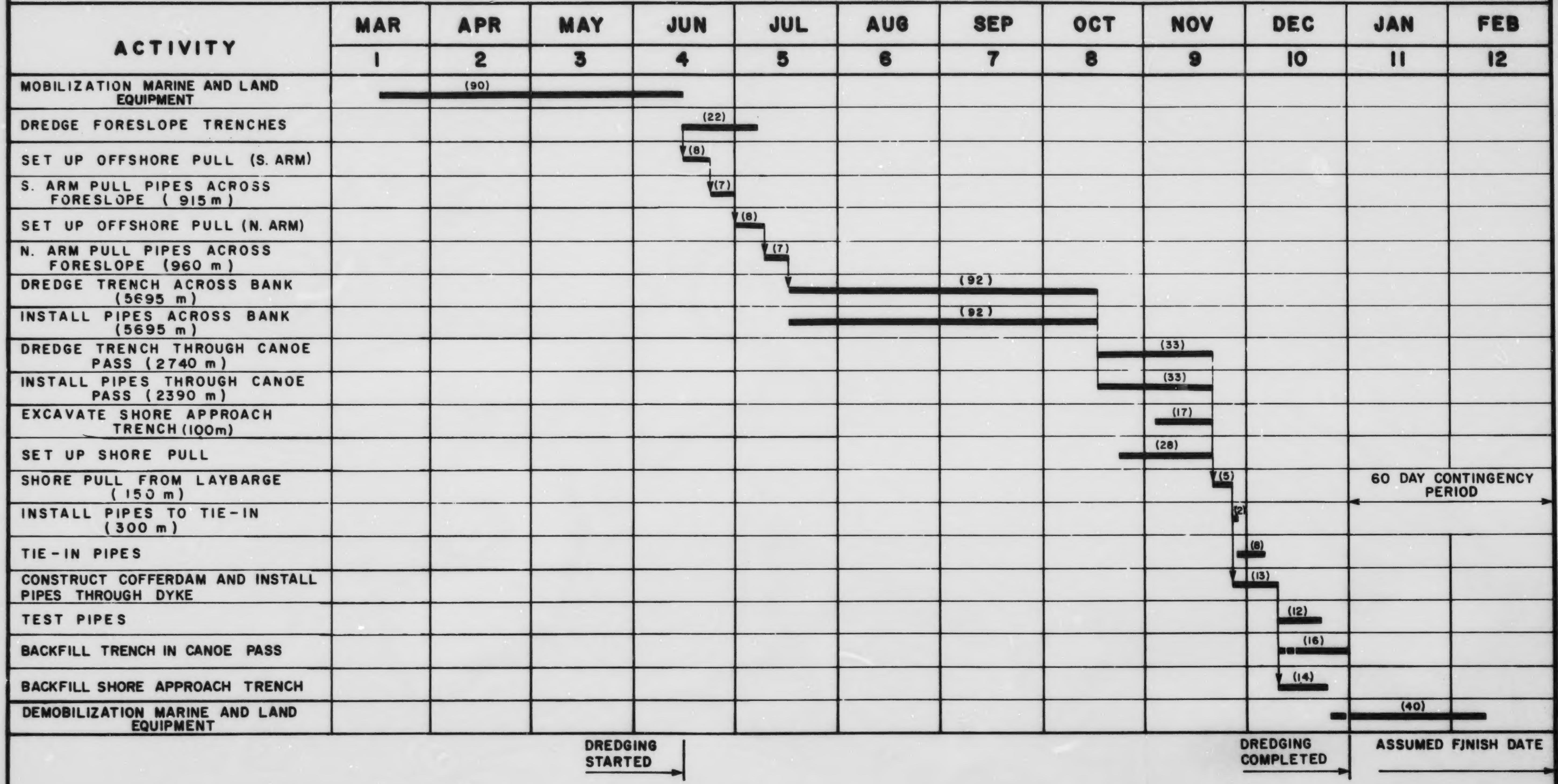

( ) NUMBER OF CALENDAR DAY

FIGURE 3
B.C. HYDRO AND POWER AUTHORITY
VANCOUVER ISLAND GAS PIPELINE PROJECT

LANDWARDS CONSTRUCTION SCHEDULE

equipment mobilization not shown in Figure 3. A 60-day contingency period was allowed (Jan. 1 to Mar. 1) in the event that unforseen events caused the dredging period to be extended.

The landward schedule satisfies points a, b, d, and f, and partially satisfies points c and e. Points g and h are not met by the landward schedule, but would be satisfied by the seaward schedule.

With respect to wildlife there are two important considerations relative to scheduling - direct waterfowl disturbance, and marsh restoration. We feel that habitat concerns, because of their long-term implications, are usually more important than temporary direct disturbance of the birds, and also that marsh restoration could be significantly easier with winter than with summer disturbance. Therefore, if there is to be direct physical disturbance of a significant amount of vegetated tidal marshland, we think that the landward schedule would be preferable. If direct disturbance is the only major wildlife concern, then the seaward schedule would be preferable for wildlife.

5.2 Wildlife Impacts

Impacts on wildlife could arise from direct disturbance as a result of construction noise and activity, or indirectly via impacts on wildlife habitat. The indirect pathways by which the birds and mammals could be affected are complex, and not analysed in detail in this report. Potential impacts on the physical environment are generally outlined by Monenco (1981). Effects on other components of the marine environment of importance to wildlife, particularly benthic invertebrates, fish, and marsh vegetation, are the subject of another report (Kistritz 1982).

5.2.1 Construction Noise and Activity

Noise generated by equipment such as the dredge, land-based digging equipment, work boats and winches would disturb most wildlife in the immediate vicinity, as would the regular movement of tugs, barges, and crew boats. Since work would continue on a 24-hour basis, displacement from local habitats would probably persist for the duration of construction in any one area. Most wildlife occurrence of concern in this regard is in the inshore part of Roberts Bank, i.e. between the Brunswick Point dyke and Canoe Pass, or in closely adjacent areas.

With the landward construction option, disturbances in or near the foreshore marshes would mostly occur from late October until the end of December, and possibly later (Figure 3). This is the period of maximum use of this area by dabbling ducks, snow geese, and swans. Those birds could conceivably be displaced to less productive or more crowded habitats, resulting in reduced over-winter survivorship and/or initiation of the spring migration and breeding season in suboptimal physical condition. This potential impact is of most concern for snow geese and swans because the Brunswick Point area is of critical importance for those species. Up to 5000 snow geese may occur at Brunswick Point (Burton 1977). However, the fact that the pipeline route largely avoids the marshlands in which waterfowl obtain food (Figure 2), and that the waterfowl species involved are already accustomed to a variety of disturbances, suggest that this impact may in fact be rather benign. It is probable that both dabbling ducks and snow geese would continue to feed in rather close proximity to dredging activity, although an exact distance cannot be stated with any certainty. Much would depend upon noise levels generated, the constancy of such noise, and the frequency and routing of support vehicles. If snow geese were displaced for a distance of one kilometer on each side of the dredging activity, then this could be a quite significant impact. A corridor one km on each side of the pipeline route would include the majority of Brunswick Point marsh and a considerable part of the Westham Island foreshore marsh. We believe however, that the zone of disturbance will be much narrower than this, thus allowing snow geese and swans to continue using most of the habitats in which they normally feed.

It should be noted that the waterfowl which occur in the Fraser Delta area from fall to spring are already accustomed to a certain amount of disturbance, i.e. marine traffic, channel dredging, aircraft movement to and from Vancouver International Airport, search and rescue hovercraft, and hunters. Thus the disturbances potentially arising from pipeline construction cannot be considered to be as severe as if they occurred in a pristine environment.

Helicopter movement, even though intermittent in comparison to dredge operation, could be an impact of concern. Barry and Spencer (1976) reported that helicopters at low levels were the most disturbing factor for birds in an area of oil well drilling in the Mackenzie Delta. Fry (1980) noted that helicopters occurred frequently over or near the Fraser Delta foreshore marshes (present on 5 of 13 survey days), but that dunlins showed a strong reaction to them, a reaction not elicited by fixed-wing aircraft. It appears that birds do not adapt as readily to the presence of helicopters as to other vehicles in their environment.

Several authors have noted that sport hunting has had a considerable influence on distribution, habitat selection and feeding flights of waterfowl in the Fraser Delta. Munro (1943) and Burgess (1970) both noted that daytime field-feeding by dabbling ducks ceased with the start of the hunting season, and was replaced by night-feeding. Burgess also found that the well defined night and morning feeding flights of dabblers ceased entirely about one week after the close of the hunting season, and concluded that "This is probably further evidence... that hunting is involved". Burton (1977) noted that during the goose hunting season snow geese largely vacated the Brunswick Marsh during daylight hours, which they spent in the Reifel Refuge, and made nocturnal feeding flights to Brunswick Marsh. Canadian Wildlife Service staff acknowledged (personal communication) that marsh habitats in the Reifel Refuge portion of the Westham Island foreshore are heavily utilized in comparison to those outside of the refuge. We feel that the pipeline dredging program would have much less impact on waterfowl habitat use than does hunting, an influence which waterfowl management agencies appear willing to accept.

5.2.2 Impacts on Wildlife Habitat

Foreshore Marshland

The inner, vegetated part of Roberts Bank is by far the most important part of the bank for wildlife. This is because it provides bulrush rhizomes and aerial shoots critical to the diet of snow geese and swans, sedge and bulrush seeds eaten extensively by dabbling ducks, and nesting sites for species such as marsh wrens and blackbirds. However, probable siting of the pipeline route is such that the Brunswick Point Marsh is crossed at a very narrow point near its northeast extremity. Of the 9.5 km distance which the pipeline would follow across Roberts Bank, less than 200 m or about 2% of that distance is through vegetated foreshore marshland - the remainder is in Canoe Pass (2.8 km) and across the intertidal sandflats (5.75 km) and delta foreslope (.75 km). Based on a 120 m wide working area through the marsh between the dyke and Canoe Pass (Monenco 1981), up to 2.4 ha of vegetated marshland could be disturbed. Of this only about 0.85 ha would actually be excavated. Based on measurements presented by Burgess (1970) and Burton (1977), the 2.4 ha of potential disturbance represents about 1.5% of the Brunswick Point foreshore marsh, 0.34% of the Roberts Bank foreshore marshes, and 0.16% of the Fraser Delta foreshore marshes. Not all of the working area would be completely disturbed. In the outer part of the marsh the cutter/suction dredge would dredge a "bathtub" varying from 85 to 65 m in width, and marshland peripheral to that should be little disturbed. In the inner 100 m of the marsh, the ditch excavated by clamshell dredge and land-based equipment would have a top width varying from 45 to 30 m. However, some marshland peripheral to that would be disturbed by placement of working pads, stockpiles of excavated material, construction of the coffer dam, and related activities. Nevertheless, it is probable that some marshland within the 120 m working area would remain partially or entirely intact upon completion of the pipeline project.

The portion of the Brunswick Point marsh through which the pipeline would pass is considered to be a mature part of the marsh, and of less value to dabbling ducks and snow geese than the outer, more dynamic part of the marsh (outer portion of sedge zone; bulrush zone). Also, being near the dyke it is currently subject to more disturbance than the other parts of the marsh. From the point of view of pipeline location then, the proposed alignment is considered to be one of the least damaging that could be found.

It must be noted however that the foreshore marshland type of wildlife habitat is very restricted in areal extent in British Columbia, and disturbance of even 2.4 ha of it cannot be taken lightly. The extent to which wildlife use of the Fraser Delta foreshore marshes would be reduced by loss of 0.16% of the marsh area probably could not be measured, but in the event that the disturbed area was permanently lost (it is not expected to be) the capacity of the Fraser Delta foreshore to support dabbling ducks and snow geese would likely be reduced by a similar percentage. Even though the Brunswick Point foreshore, in comparison to other parts of the Fraser Delta foreshore, has above-average importance for snow geese, long-term impacts on that species are not expected to be greater than the proportion of habitat disturbed because most use by geese is in the outer part of the marsh which will not be directly affected by pipeline construction.

Kistritz (1982) has suggested that construction activity impacts in Brunswick Marsh would be least damaging to the vegetation during the period November to March because below-ground energy reserves would be fully replenished before construction began. He also noted that the area of total disruption would be small in area and short in duration, and felt that with proper and careful procedures during construction and restoration, new plant growth could be expected during the subsequent growing season. However, it is difficult to predict the distribution patterns of plant species which will grow on the disturbed site over a period of years following disturbance.

Canoe Pass

This segment of the Roberts Bank crossing is of relatively little importance as wildlife habitat. Wildlife use here primarily involves feeding on migratory fish - either downstream moving juvenile salmonids or upstream moving eulachons - both of which occur in spring. The wildlife species involved are primarily seals, loons, grebes, mergansers, and cormorants. These species would only be affected by pipeline construction to the extent that habitat changes caused their fish food to be less available. The dredging program (landward dredging) has been planned so that it will not interfere with spring and early summer fish occurrence, and therefore there is expected to be no significant impact on piscivorous wildlife.

Sandbars used by seals as temporary haul-out sites are along the edge of Canoe Pass west of the pipeline, and should not be affected.

Intertidal Sandflats

The strip of habitat which would be dredged across the sandflats is of fairly minor importance to wildlife. Use of the sandflats is primarily for loafing (at low tide) or for feeding on invertebrates (higher tides).

Dredging across the sandflats will disturb about 40 ha of habitat, but will not result in permanent destruction. Wildlife food sources here are primarily benthic invertebrates such as clams which are eaten by diving ducks. The area to be dredged is only about 0.6% of the total area of sandflats at Roberts Bank. In addition, changes in substrate type will generally be relatively minor and recolonization of the dredged area should be fairly rapid, i.e., largely complete within one year (Kistritz 1982). Therefore we feel that dredging across the intertidal sandflats should have a negligible impact on wildlife.

Delta Foreslope

More waterfowl feeding (per unit area) probably occurs at the upper foreslope than on the sandflats because invertebrate biomass is considerably higher on the slope (Kistritz 1982). However only about 9.5 ha of benthic habitat will be dredged and, as in the case of the sandflats, recolonization should be fairly rapid. Therefore, no measurable impact on wildlife should occur.

6. MITIGATION MEASURES

6.1 Control of Direct Disturbance

Duration: Direct disturbance will be proportional to the amount of time that construction activities occur in and near the marshes. Construction, testing, and demobilization in this area should be carried out as quickly as is compatible with engineering constraints and other environmental concerns.

Control of noise and activity: Noises from construction machinery should be muffled to whatever extent is feasible. Movement of crew launches, tugs and barges should be as infrequent as possible and confined to the work area. Use of helicopters and hovercraft should be avoided if possible. If not possible, movements of those craft should also be restricted to the work area. Helicopters flights should not be directly over the foreshore marshes, or should be of sufficient height to preclude significant disturbance. Barry and Spencer (1976) noted that "altitudes of 150 m seemed a satisfactory height for slight disturbance on most occasions...".

6.2 Control of Habitat Damage

The matter of preservation and restoration of marsh vegetation is the subject of other studies, and will not be considered in detail here. However, the major considerations of importance to wildlife are listed below.

Work area: The work area should be as narrow as possible, and no unnecessary activities should occur outside of it. If anchors must be placed in marshland outside of the work area, this should be done with great care. Within the work area, as much as possible of the surface soil layer containing roots and propagules of marsh plants should be stockpiled separately from underlying material and replaced on the surface when backfilling is completed. Pads on which land-based machines are placed should be of such design to cause minimal impact on the surface soil and roots of marsh plants.

Revegetation: A serious attempt should be made to re-establish native plant species wherever the pipeline right-of-way passes through vegetated marshland. This should continue until such re-establishment is considered to be successful. It is not the purpose of this report to recommend how this can best be done. However, it must be stressed that vegetation establishment is important if existing wildlife uses in the disturbed area are to be resumed, and if erosion of adjacent wildlife habitats is to be prevented.

Backfill material: Backfill material should not be obtained from locations that are currently important wildlife habitat. Backfill material placed within the marshlands should be of similar composition and quality to material already there, i.e., should be capable of supporting those marsh plants which presently occur and provide wildlife food or cover.

Potential pollutants: Great care must be taken to ensure that diesel fuel, hydraulic fluids and related compounds used by construction machinery do not enter the marsh. Petroleum products can have long-lasting effects on marsh vegetation (Kistritz 1982) as well as a direct and fatal impact on wildlife, particularly birds.

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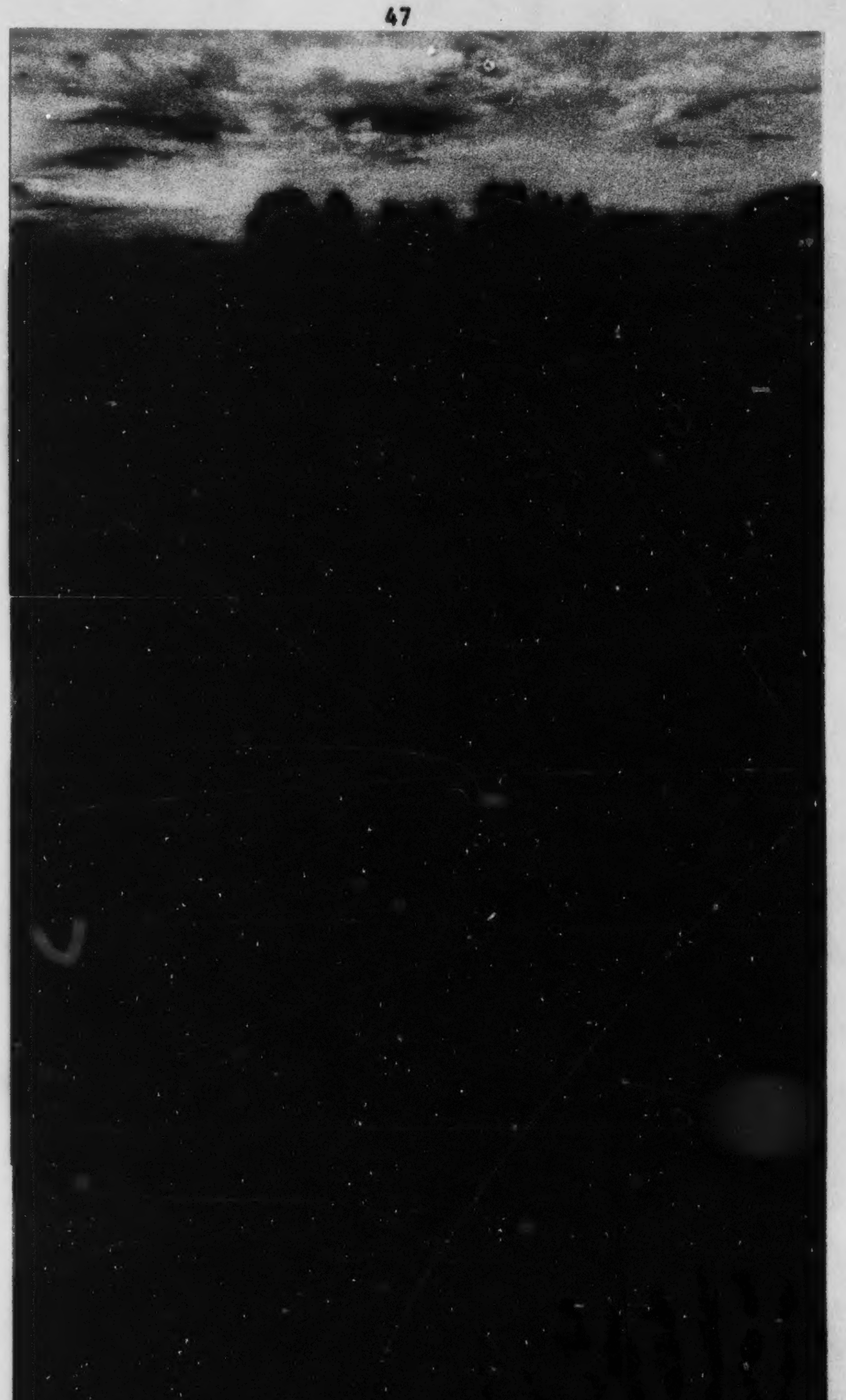
PHOTO's

1. Cannery buildings and dense shrub cover adjacent to the dyke at Brunswick Point, used by a variety of passerine birds. Rabbits also use these areas and the shrubbery provides cover for ring-necked pheasants.

2. The photo shows the tidal marshes from the Brunswick Point dyke toward Canoe Pass. Vegetation in the immediate foreground (bottom of photo) is part of the mixed grass-forb riparian zone; that in the middle distance is primarily sedge with patches of cattail bulrush; far background vegetation is primarily bulrush of the genus *Scirpus*. This photo was taken in July when vegetation growth was more or less complete.

3. This is approximately the same area as Photo 2, however this picture was taken in May when the marsh vegetation was still low. The small ponds in the foreground were often frequented by dabbling ducks and shorebirds.


1
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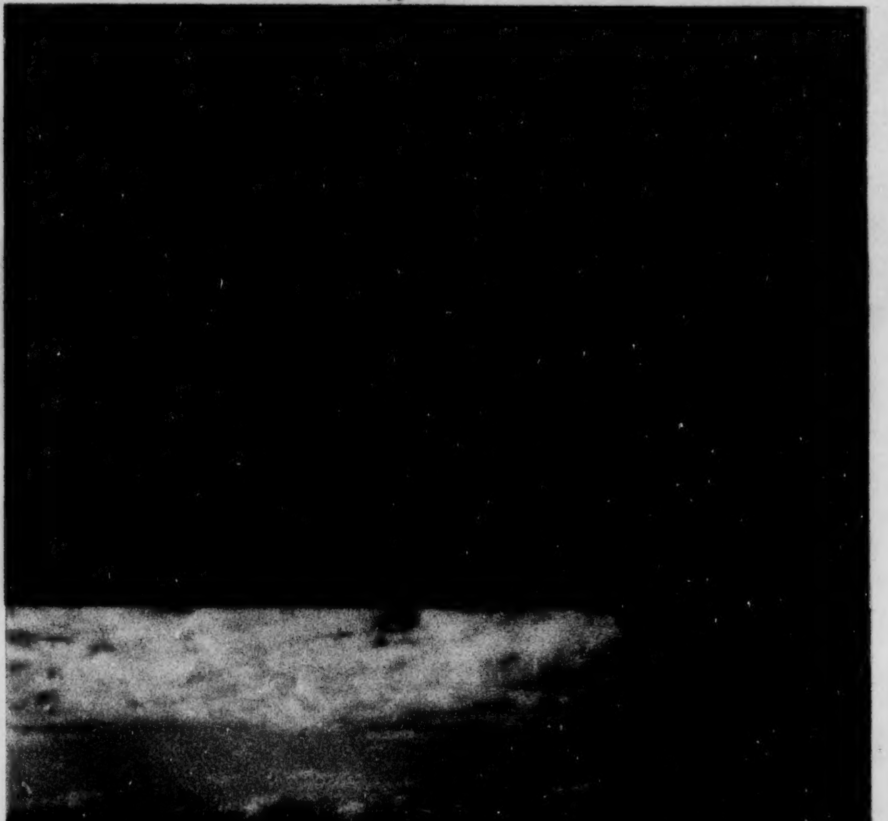
4. This is a large channel dissecting the Brunswick Point marsh. This is a favourite feeding site for ducks, herons and shorebirds, and sometimes used by swans. Avian foods here include invertebrates in the mud or sand (eaten by shorebirds), sculpins or other fish in tidepools (herons), sedge or bulrush seeds on or in the sand (dabbling ducks) and low bulrush growth on either side of the channel (geese). This photo was taken at low tide.

5. A cattail marsh just south of the proposed pipeline route. These important marsh habitats are used by ducks, shorebirds, blackbirds and marsh wrens.

6. A marsh wren nest in a cattail stand, Brunswick Point marsh.

4



5

6

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

VANCOUVER ISLAND NATURAL GAS TRANSMISSION/DISTRIBUTION SYSTEM

TERMS OF REFERENCE FOR

DESCRIPTION OF WILDLIFE USE OF ROBERTS BANK AND ASSESSMENT OF IMPACTS OF PROJECT ON THAT WILDLIFE

1. GENERAL

B.C. Hydro is considering extending its natural gas transmission/distribution system to and on Vancouver Island by underwater pipeline from the Lower Mainland. As part of the project, transmission and distribution systems would be constructed on Vancouver Island to serve all major load centres between Campbell River and Victoria, including the Alberni area, thereby making gas available to about 80% of the Island population.

As part of the regulatory requirements for this project, B.C. Hydro must produce an environmental impact assessment study covering construction and maintenance of the project in a designated area of Roberts Bank.

The designated area is bounded in the north by the Steveston North jetty, on the east by the dykes, on the south by the Roberts Bank Port, and on the west by the toe of the Fraser-Delta foreslope.

The consultant will be responsible for production of a report, in a format to be agreed with B.C. Hydro, describing the use of the study area by wildlife; assessing the probable impacts of project construction and maintenance on wildlife; identification and assessment of mitigation opportunities; collection of further field data, as agreed.

2. SCOPE OF WORK

2.1 Review of existing data and information on use of area by birds, aquatic mammals and other wildlife.

2.2 Definition of seasonal variation in patterns of use of study area by wildlife.

2.3 Collection of further field data, if necessary (Budget for this item to be shown separately).

2.4 Assessment of probable impacts of alternate methods of project construction and maintenance on wildlife assuming use of laybarge method of construction and either a shorewards or seawards direction of movement.

2.5 Identification and assessment of opportunities for mitigation of adverse impacts on wildlife.

2.6 Production of report covering Clauses 2.1 to 2.5.

2.7 Meeting with B.C. Hydro and other consultants at start of study, and to review impacts and determine the preferred method of construction and construction schedule, and consider mitigation opportunities.

2.8 Review of EIS prepared by B.C. Hydro.

3. B.C. HYDRO WILL PROVIDE

1. Copies of reports on Roberts Bank Coal Port expansion and proposed Fraser River Training Walls.

2. Description of construction and maintenance methods and schedules to be considered and their impacts on physical environment.

3. Map of Roberts Bank showing proposed route and reserve and associated aerial photos and mosaics.

4. FINAL REPORT

The report shall be submitted in draft form in three copies for review prior to submission of the formal report.

The consultant shall submit a final report in twenty copies. The report shall be complete with photographs, sketches and all other pertinent descriptive material. The individuals who made significant contributions to the work shall be identified by name in the report.

5. EXPERT WITNESS

The consultant will, if requested, provide competent witnesses to testify to the report before a third party and cross examination by intervenors and/or competing applicants. Acceptance of this assignment shall preclude testimony by the selected consultant on behalf of competing applicants or intervenors on matters relating to the scope of work contained within the assignment.

6. CONFIDENTIAL INFORMATION

All information provided by Hydro and all material generated during this assignment is, and shall remain confidential unless the specific written consent of Hydro provides otherwise.

7. SI UNITS

SI Units as designated by the "B.C. Hydro Metric Handbook" shall be used throughout the report. The B.C. Hydro Metric Handbook is consistent with the "Metric Practice Guide, CSA Can 3-Z 234.1-76", and the CGA booklet "SI Units and Conversion Factors for the Canadian Gas Industry". Copies of the handbook are available on request.

8. SCHEDULE

The draft report shall be submitted by 15 May 1981 and the final report by 15 June 1981. Within ten calendar days of award of the contract the consultant will submit a written schedule for performing the work.

9. PROGRESS REPORT

The consultant will provide on the first working day of each calendar month a brief statement of:

- work done in the month;
- percent of job completed;
- expenditure in the month;
- percent of authorized expenditure spent;
- a list of the names of people contacted who are outside of B.C. Hydro and the company performing this work.

The consultant shall maintain a close contact with B.C. Hydro's designated contact Mr. K.G. Farquharson.

10. PAYMENT

Charges for the work will be on a per diem basis in accordance with an approved scale of fees plus out-of-pocket expenses at cost. Invoices shall be submitted monthly and supported by a statement showing the names of individuals, number of hours charged and the applicable rate.

Out-of-pocket expenses shall be supported by invoices or other acceptable documentation. Unless otherwise stated, terms of payment shall be net 30 days. Charges for work shall not exceed $10,000, without prior written authorization.

11. RIGHT OF AUDIT

The party providing the professional services hereunder shall permit representatives of B.C. Hydro at all reasonable times, to inspect and audit all his records, accounts, statements and other documents relating to such services and shall keep such records, accounts, statements and documents for at least one year after completion of the assignment to supply such services or for such extended period as B.C. Hydro may require in writing delivered to such party in advance of such completion. The liability of B.C. Hydro to make any payment shall be subject to the right of B.C. Hydro to inspection and audit as above provided.

Such party shall make this clause a condition of subcontracting any portion of such services.

12. TERMINATION

B.C. Hydro shall have the right to terminate the work at any time during the duration of the assignment. B.C. Hydro will pay for the consultants time expended and expenses up to and including the termination date.

13. PERFORMANCE

The Consultant, in performing his duties, shall at all times act in the best interests of B.C. Hydro and exercise at least the degree of skill, care and diligence required by customarily accepted professional practices and procedures normally provided in the performance of such services.

14. COOPERATION

The Consultant and his staff shall cooperate with any other Consultants hired by B.C. Hydro to undertake related programs for the same project, and on request, shall make available to such Consultants all pertinent information gathered or produced for this project.

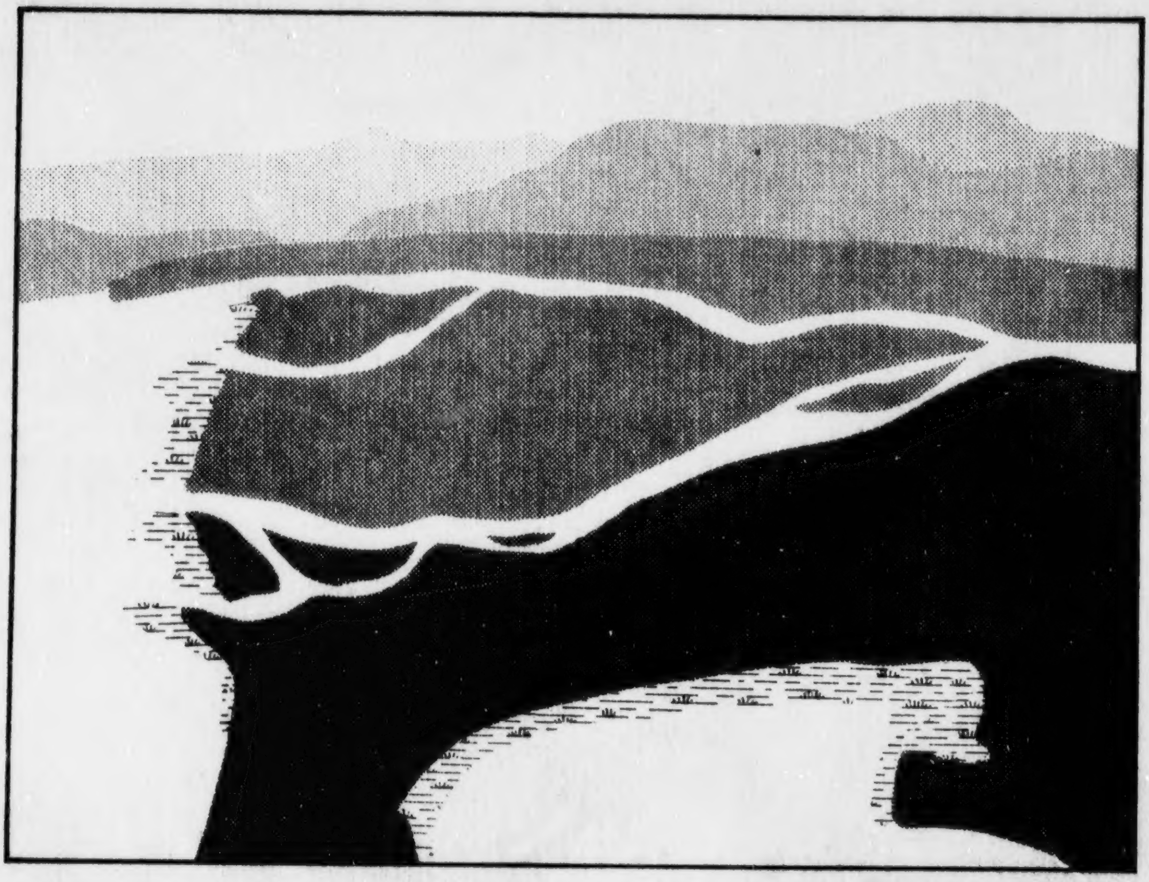
K.G. Farquharson
27 February 1981

Volume

5

Ex 114E

ENVIRONMENTAL IMPACT ASSESSMENT OF CONSTRUCTION OF A NATURAL GAS PIPELINE ACROSS ROBERTS BANK



Volume 5: The Potential Impact of Pipeline Construction on Public Use of Roberts Bank

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February, 1983

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ENVIRONMENTAL IMPACT ASSESSMENT OF CONSTRUCTION OF A NATURAL GAS PIPELINE ACROSS ROBERTS BANK

VOLUME 5

THE POTENTIAL IMPACT OF PIPELINE CONSTRUCTION OF PUBLIC USE ON ROBERTS BANK

B. C. HYDRO
FEBRUARY, 1983

CYPRESS RESOURCE CONSULTANTS LTD.

CR13J

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1.0 INTRODUCTION

Under the terms and conditions of Provincial Order in Council 908, B. C. Hydro is required to prepare a detailed environmental impact statement concerning that portion of the proposed Vancouver Island natural gas pipeline that will cross Roberts Bank.

The area to be included in this investigation is described in the Terms of Reference as .." Roberts Bank, from the Steveston North Jetty south to the Roberts Bank Port, bounded on the east generally by the dykes, and on the west by the toe of the Fraser River delta foreslope". The study was to examine the impacts of pipeline construction and operation on the physical and biological environments, and on public use. This report addresses the latter component, specifically the nature, location and seasonality of public use in the subject area, and identifies the degree to which public use might be affected by the project. The types of use that were considered in this study include recreational, commercial and Indian food fishing activities.

Little published information pertaining to the pattern of public use in this specific area was available. As a result, the following descriptions of public use in the vicinity of Brunswick Point and Canoe Pass frequently refer to an area larger than that to be disturbed by pipeline construction activity, or affected by the pipeline right-of-way. To a large extent, published sources of information dealing with recreation, boating and commercial fishing, in the Fraser Estuary, for example, have been drawn upon, though every effort has been made to refine the existing information through direct contact with various government agencies, private enterprises, recreation organizations and knowledgable individuals. Information on pipeline construction activities and scheduling was based on the accompanying report entitled "Impact of Construction on the Physical Environment of Roberts Bank", by MONENCO Pipeline Consultants Ltd.

2.0 COMMERCIAL FISHING

Commercial fishing in the study area includes the salmon fishery, ground fishery and the harvesting of certain types of shellfish, primarily crab and shrimp. All these activities are seasonal, and are closely regulated by either the Federal Department of Fisheries and Oceans, (DFO), or the International Pacific Salmon Fishing Commission (IPSFC), or both.

The Fraser River system supports the most productive fishery in British Columbia. Roberts Bank and Canoe Pass form the southernmost portion of the Fraser Delta, and have major significance not only from the point of view of aquatic habitat, but also that of harvesting of the fisheries resource.

2.1 Salmon Fishery

Management of the commercial salmon fishery is the joint responsibility of the International Pacific Salmon Fishing Commission (IPSFC) and the Department of Fisheries and Oceans (DFO). Roberts Bank and Canoe Pass lie within District #1 as defined by the IPSFC. This District is managed by the IPSFC usually between the third week of June, at the start of the season, and mid-October of each year. DFO retains the responsibility of fisheries management for the remainder of the year.

The IPSFC has regulated the commercial fishery for sockeye and pink salmon since 1946 at which time the commercial openings averaged about four days per week between June and October. Since that time, the period of opening has been steadily reduced - partly in reaction to declining stocks and the desire for stock conservation. In 1977, openings averaged 1.7 days per week, and more recently, 1 to 1.5 days per week have been common. The openings for 1981 were limited to 1 day per week (8:00 a.m. Monday - 8:00 a.m. Tuesday) between 29 June and 14 September.

In a given year, variations in this schedule may occur depending on the size of the run, timing of fish migration and so forth; for example, extensions may occur if the runs are larger than anticipated, or if Canadian fishermen are in the position of having to "catch up" with their American counterparts, as the American fishermen take fish at an earlier stage in the fish migration. The IPSFC retains control of commercial openings until mid-October thereby allowing for the opportunity to extend openings between mid-September and mid-October.

Records from the IPSFC show the pattern of commercial fishing opening totals in District 1 since 1979:

1979 - 11 days
1980 - 13 days
1981 - 11 days (unless extended)

The individual openings range in length from 24 hours to 72 hours.

The IPSFC, in addition to regulating the timing of openings, can also impose closures over certain areas that lie within treaty waters. The closures that are most often imposed on fishing activities in the Fraser Delta and Georgia Strait are defined by the "Blue Line", or the "Georgina Point Line". These lines are shown on Figure 2. Closures usually refer to that area east of the line, thus Roberts Bank and Canoe Pass could be closed to commercial fishing during either a Blue Line or a Georgina Point Line closure. The intent of these closures is to prevent excessive harvesting of salmon when they are congregated over Roberts and Sturgeon Banks prior to moving up the Fraser River. It is not possible to forecast the occurrence of these closures, as they are dependant on daily observations of fish migration, and are imposed at the discretion of the IPSFC and DFO.

Fishing effort varies from year to year depending on the size and timing of the fish runs. Sockeye salmon are the main commercial species taken in the study area. These fish are present every year, but major runs, such as the Adams River run, occur every four years. The last Adams run occurred in 1982; the next run will occur in 1986. Dominant runs of pink salmon occcur in odd-numbered years, but the abundance varies and it is difficult to estimate the strength of the run until a few months prior to the start of fishing season in any given year. Other species of salmon are present each year; chinook tend to occur in early spring through summer, chum and coho are present in summer and fall.

Local fisheries officers were contacted for information concerning the level of fishing effort on Roberts Bank and in Canoe Pass. It was estimated that between 75 and 200 boats fish between the Steveston Jetty and the Roberts Bank superport during commercial openings. The fishermen tend to fish at depths greater than 3-5 fathoms, although some fish in Canoe Pass as shallow as a three foot tide in the channel. The channel, however, is only open during full river openings.

Statistical areas 29A and 29B (see Figure 2) are only open to gillnet fishing. Thus the main species of salmon caught in this area are sockeye, pink and chum. There is also an incidental harvest of chinook salmon, though these fish are generally caught by trolling. The following catch statistics are reproduced from the B. C. Catch Statistics for 1979 and 1980.[1]

---

1. British Columbia Catch Statistics, 1979. Fisheries and Oceans, Fisheries Management. Pacific Region.
   ________ 1980.

Statistical Areas 29A and 29B are not separated, therefore it is difficult to estimate the proportion of effort attributable to 29B which covers Roberts Bank and Canoe Pass. The total volume of salmon caught in Areas 29A and B over the last few years is given below:

	1978	1979	1980
Landed Weight (metric tons)	2,138	2,333	870*

* Fraser River was closed for part of the season due to poor salmon runs.

Fishermen who fish along Roberts Bank access this area from Steveston via the main arm of the river, and from Ladner via Canoe Pass. Approximately 30-40 commercial fishing vessels use Canoe Pass regularly during the season. The boats are moored along Canoe Pass between Ladner and the Westham Island bridge; and at the Harbour Park Marina in Ladner. This marina has capacity for 36 boats and is fully occupied at present primarily by commercial fishing vessels. Some of these vessels use Canoe Pass, others use the main channel via the Steveston Jetty to access Georgia Strait. It is anticipated that use of Canoe Pass will increase slightly as fishermen become more familiar with the channel and the newer bathymetric charts of this area which identify the channel markers.

2.2 Crab Fishery

Crab fishing for commercial purposes occurs along the crest of the delta foreslope along Roberts Bank, and to a lesser extent, Sturgeon Bank.

Crabs are harvested throughout the year with the exception of the period between 15 May and 15 June when the soft shell closure is in effect. DFO may extend the soft shell closure, however, as it did in 1981 when the closure was effective from 1 April to 30 June. For reasons that are not well understood, the incidence of soft shell crabs varies from year to year, and this determines the length of closure.

Crabs are generally taken between 1 and 15 fathoms between the Tsawwassen Jetty and Sandheads, as shown in Figure 3. The annual harvest of crabs in Area 29A and 29B for 1979 and 1980 was 113 and 142 metric tons respectively; the 1980 catch involved 1,374 man-days of fishing effort.

In the Ladner/Canoe Pass area, there are roughly 10-12 full-time crab fishermen, as well as several salmon fishermen who participate in the crab fishery after the close of the salmon fishery in the late fall.

Crab fishermen use Canoe Pass on a regular basis throughout the year. During the peak period of harvesting, usually between mid-summer and early fall, it is usual for crab fishermen to make daily trips to check their crab pots. Later in the fall and during the winter, the frequency of trips dwindles to approximately 2-3 times per week.[1]

2.3 Shrimp Fishery

The shrimp fishing is restricted to that area west of the "Blue Line". The reason for this is that shrimp are caught in trawl nets, and trawling is not permitted east of the "Blue Line".

Most of the shrimp fishermen are also salmon fishermen, therefore it is difficult to estimate the number of fishermen that fish commercially for shrimp. Regional fisheries officers estimate that roughly 6-10 fishermen are active in the commercial harvest of shrimp, although most of this effort is centered off Sturgeon Bank rather than Roberts Bank. The combined annual harvest of shrimp in Areas 29A and B, which encompasses Roberts and Sturgeon Banks, was 62 metric tons in 1979 and 56 metric tons in 1980.

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[1] Mr. E. Birch, pers. comm. 1981.

Shrimp are taken throughout the year, except during the closure from 1 March to 31 March.

2.4 Ground Fishery

Groundfish include a variety of species, such as lemon sole, cod, flounder, rockfish and pollack. All of these are caught with trawl nets which are dragged along the seabed, with the exception of pollack which are caught with a mid-water trawl. As with shrimp, the ground fishery is restricted to the deeper water off Roberts and Sturgeon Banks. A 1981 regulation restricts trawling to that area west of the 50 fathom contour along the delta foreslope; the reason for this is to minimize the incidental capture of crabs.

The key areas for ground fishing in Georgia Strait are Statistical Areas 17 and 18, covering the waters around the Gulf Islands. It is estimated that four fishermen from the Steveston area actively participate in ground fishing on a regular basis; others will occasionally come across Georgia Strait from the Gulf Islands to fish along Roberts and Sturgeon Banks.[1] The groundfish catch in 1980 totalled 713 metric tons in Areas 29A and B and involved 400 fishing days of effort.[2]

---

1. J. Lewis, DFO. pers. comm. 1981

2. British Columbia Catch Statistics, 1980. Fisheries and Oceans, Fisheries Management. Pacific Region.

Ground fishing is centered more off Roberts Bank than Sturgeon Bank, and is slightly more active during the winter. The ground fishing closure covers the same period as for shrimp - March 1 to March 31.

3.0 INDIAN FOOD FISHING

Canoe Pass is open for Indian food fishing during the period between the middle to the end of March and the middle to end of October. From March to 1 July, the openings are for 12 hours, one day per week (1981 - 6 a.m. to 6 p.m. Sat.), and are managed by the IPSFC. After 1 July, the openings are extended to a 36 hour period, once per week, and are controlled by DFO.

The Indian food fishery is restricted to that area upstream of the mouth of Canoe Pass, specifically that area east of the boundary markers at the west end of Westham Island and a dolphin at the most westerly point of land on the south shore of Canoe Pass (see Figure 3).

Both the Musqueam and Tsawwassen Bands fish in Canoe Pass. A spokesman for the Musqueam Band stated that during the openings approximately 20 boats go out to fish. Although only a few families are actually fishing, the fish caught are distributed amongst the Band members; the importance of the food fishery for the Band members was stressed.[1]

The Tsawwassen Band fishes Canoe Pass, but to a much lesser extent. Approximately 5-6 boats from this Band fish in Canoe Pass at present.

---

[1] H. Grant, Musqueam Band Manager. pers. comm. 1981.

4.0 RECREATIONAL USE

4.1 Introduction

The study area forms the southwestern corner of the Fraser estuary, and supports a wide variety of recreational activities on a year round basis. Most recreational activities in this area are water-oriented, and focus on both the Fraser River and the tidal waters over Roberts Bank. Figure 4 shows the distribution of general recreation activity within the study area.

Specific natural features of this area that have significance for recreation opportunities include Canoe Pass and the adjacent river banks which provide a sheltered, riverine environment conducive to fishing, canoeing, and nature observation, the expanse of tidal flats of Roberts Bank, important for fishing, boating, and some crabbing activity; and Brunswick Point and the adjacent marshes, which provide habitat for numerous species of birds and other wildlife, and is a public hunting area of regional and local importance.

Many of these activities are seasonal in nature, depending on weather conditions, legal restrictions, such as those imposed on hunting, and seasonal changes in the surrounding environment, such as the yearly migrations of salmon and several species of birds in the Fraser delta.

Most of the following discussion on recreational use in the study area has been based on information collected through informal discussions with personnel from all levels of government, and with numerous recreation organizations and informed individuals in the region. A list of contacts is available in Appendix I.

4.2 Sport Fishing

Sport fishing in the area is generally directed toward the salmon resource, though there may be an incidental catch of groundfish as well.

Very little published information is available to document sport fishing effort in the vicinity of Canoe Pass and along Roberts Bank; a recent impact assessment of the Roberts Bank coal port expansion has identified this to be a major data gap.[1]

Sport fishing is carried out off Roberts and Sturgeon Banks, mostly by trolling from small boats. It is an activity that can be done year round, as there are no seasonal closures as there are in the commercial fishery. The majority of sports fishermen fish during the summer months, between May and September, although an increase in winter activity has been noted which would in part be due to the milder weather over the past few years.[2]

The major sports species are chinook and coho salmon, although there is an incidental catch of other salmon species and anadromous trout as well. As of January 1981, however, most of the southern portion of Statistical Area 29 has been closed to the taking of all chinook salmon until further notice. The closed area includes all of Roberts Bank and Canoe Pass.

Discussion with Federal Fisheries personnel revealed that at the time of writing, no catch statistics or angler-effort data for sports fishing in Area 29B, nor for the entire Area 29, was available. It is understood, however, that this type of information was being collected and would be available later in the year.[1] Consequently, it is impossible to estimate the level of sport fishing activity in the subject area with any degree of confidence.

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[1] Roberts Bank Recreational Impact Assessment. 1981. Draft. Ministry of Environment.

[2] Bill Masse. DFO. Economics Div. pers. comm. 1981.

Judging from the fact that the area is closed to chinook fishing, and through discussions with the regional fisheries officer, it appears as if the Canoe Pass and Roberts Bank area receives relatively minor use as compared to other areas to the north and west that are still open for chinook fishing. Canoe Pass is used, however, as a means of access to Georgia Strait; this is discussed in Section 5.2.

Crabs: Crab fishing for recreational purposes is permitted year round. Crabs, both Dungeness and Rock crabs, are found in the intertidal zone, generally near the low-tide line, and beyond this to a depth of 15 fathoms.

Crabs are frequently caught on foot at very low tides; at other times in traps deployed from small boats. Crabbing from the shore is mostly done during the summer, from May through to August, and from boats, on a year-round basis.

The most popular areas for crabbing on Roberts Bank are along the north side of the Roberts Bank Port Jetty, and along

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1. M. MacGregor. DFO. pers. comm. 1981.

the Tsawwassen Jetty. These areas are used intensively during the summer.

Crabs are also taken from boats off the Canoe Pass buoy, at the mouth of the Canoe Pass channel. It has been estimated that on good weekends, perhaps six boats have been crabbing in this general area. There is virtually no crabbing done from the shore around Brunswick Point, primarily due to the wetness of the marsh area and intertidal zone adjacent to Brunswick Point that makes foot access exceedingly difficult.

Shellfish: The entire intertidal region from Boundary Bay to Burrard Inlet is closed to the harvesting of shellfish due to bacterial contamination. The closure has been in effect for many years, and applies to all bivalve molluscs, such as oysters, clams, mussels and scallops.

4.3 Hunting

Most hunting activity in the Fraser estuary region is directed towards birds, and is closely associated with the extensive intertidal flats and inshore tidal marshes which provide a diverse habitat for several species of birds. The marshes provide habitat for several species of waterfowl, including ducks and geese. There are extensive marsh areas in proximity to Brunswick Point and Canoe Pass, specifically those that extend seaward from the western edge of Westham Island, and along the southwestern edge of Brunswick Point. Figure 5 shows the extent of these marshes as of 1980.

Many hunters hunt birds from punts or small boats that can be hand-launched over the dykes, near Brunswick Point. Small trailered boats can be launched at the commercial ramp located just west of the Westham Island bridge. Hunters using punts tend to stay within about 25 to 30 m from shore.

Westham Island is privately owned and dyked, and as a result, there is no public access to the dyke or foreshore marshes beyond the dyke, other than by boat. Hunters often make their own arrangement with landowners that allow them hunting priviledges along the Westham Island dyke, and access to the adjacent marshes. In contrast, the dyke surrounding Brunswick Point and extending south to the superport jetty is open to the public, hence hunting pressure at Brunswick Point has been increasing relative to that on Westham Island.

The hunting season traditionally starts on the Saturday of the Thanksgiving weekend, which usually comes in mid-October, and lasts until about 10 March on a continuous basis. Within this time period, however, different species of birds are hunted at different times. The regulations that apply to birds hunted in the Brunswick Point area are as follows (for 1980):

11 October - 25 January	open for ducks
11 October - 30 November	open for snowgeese
25 January - 10 March	open for snowgeese
1 March - 10 March	open for brant

The seasonal openings and catch limits are established by the Canadian Wildlife Service under the Migratory Birds Act. The length of openings and catch limits are reviewed annually, based on cursory bird counts carried out by the local authorities of the Canadian Wildlife Service and Provincial Fish and Wildlife Branch. In fact, though, these openings are rarely varied and have essentially become a tradition.

The magnitude of hunting effort at Brunswick Point and in the adjacent marshes is difficult to estimate without specific data collection in this area. The most recent estimate of hunting was made in 1978, by the Recreational Work Group of the Fraser River Estuary Study. In the 1976-77 hunting season, it was estimated that hunting effort totalled 77,160 hunter-days in the Fraser Estuary Lowlands, of which 4,296 hunter-days occurred at Brunswick Point, and 9,688 hunter-days at Westham Island.

Local rod and gun clubs were contacted for comment on the project and for any additional information concerning the level of hunting in the vicinity of Brunswick Point. It was repeatedly stated that Brunswick Point is favoured hunting area of local hunters, and is especially popular for snowgeese hunting. Estimates of use varied considerably, with figures mentioned of "35 - 40 hunters on good days" and "about 200 guys with no place to park on Saturday mornings".

In summary, Brunswick Point and the adjacent marshes appears to be a popular location for hunters, and is used intensively during the period between mid-October through mid-March.

4.4 General Recreation

Activities:

In addition to the opportunities for sport fishing and hunting, Brunswick Point and the adjacent marshes provide for a variety of other recreational activities on a year round basis.

The marshes adjacent to Brunswick Point and Westham Island are attractive canoeing and kayaking places where the interesting tidal marsh vegetation and several species of birds can be observed. The tidal marsh is particularly attractive in the summer when the flowers are in bloom; birds are present at all times during the year, but are most abundant during the fall and winter months when the migratory species are over-wintering in the marshes and adjacent tidal flats.

There is a dyke along the shoreline that extends more or less continuously from the Westham Island bridge to the Tsawwassen Jetty. The dyke provides pedestrian access to the shore and the marshes beyond. South of Brunswick Point, the dyke has a wide, flat, gravel surface, and is ideal for walking, jogging, cycling and horseback riding, while providing a good view across Georgia Strait to the Gulf Islands, and the Roberts Bank coal port to the south.

It is possible to walk along the dyke, although public use is discouraged by the presence of signs warning of trespass, and the Brunswick Cannery which straddles the dyke at the Point and appears impassable. The cannery is one of the oldest salmon canneries on the Fraser River and has some local historic interest. It was recently learned, however, that the B. C. Harbours Board, the owners of the site, intend to demolish the cannery and ancillary buildings in 1982.

The dyke adjacent to the Brunswick Point marsh is a popular place for wildlife viewing. This is one of the few areas along the foreshore that is accessible to the general public, where a large variety of birds can be observed at close range. Some of the species frequently sighted include gulls, ducks, herons, cormorants, marsh hawks, grebes and sandpipers. In the winter, trumpeter and whistling swans and snowgeese can be seen.

Recreational Use:

Due to the abundance of wildlife, its proximity to major population centers, and the fact that the dykes provide public access to the foreshore, Brunswick Point is intensively used by naturalists, especially during the fall and winter. Many individuals, as well as organized naturalist groups and educational groups visit the area each year.[1]

Other than the estimate of hunting effort reported in Section 4.3, there is virtually no accurate information concerning the level of recreational use that occurs in the vicinity of Brunswick Point. Contact with the Vancouver Natural History Society revealed that a number of avid bird watchers visit Brunswick Point frequently during the fall and winter seasons. Of 15 members contacted (out of a total membership of approximately 1,000), an average of ten to fifteen trips per year were made.

Vehicle Access:

Vehicle access to Brunswick Point is by way of River Road West which ends just east of the cannery. There is limited parking space at the north end of Mason Road. The dyke can also be reached by car at the west end of Matheson Road (Deltaport Way), at the Roberts Bank Port Jetty.

5.0 MARINE TRAFFIC

5.1 Introduction

Construction of the marine pipelines across Roberts Bank will require crossing Canoe Pass and construction of the shore approach trench between Canoe Pass and Brunswick Point. This activity will involve obstruction of the channel for approximately two months.

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1. K. Hobson, Vancouver Natural History Society. pers. comm. 1981.

Canoe Pass is a recognized navigable channel, and is marked with a series of dolphins out to the 15 fathom contour. The Canadian Coast Guard is responsible for maintaining the channel markers.

Both commercial and pleasure craft use Canoe Pass, although it is understood that due to the navigational problems inherent in the narrow, shallow channel, and the width and height restrictions imposed by the Westham Island bridge, that larger tugs and barges do not generally use Canoe Pass; nor is it used by tugs towing log booms, or for log storage.

Movement of deep sea vessels is concentrated within the commercial shipping lanes in Georgia Strait, and as such, will not be directly affected by the construction activity on Roberts Bank. Laying the pipelines across Georgia Strait may, however, require some adjustment of shipping lanes, and approval under the Navigable Waters Protection Act will be required for this section of construction. Similarly, deep sea vessels using the South Arm of the Fraser River via Steveston will not be directly affected by pipeline construction on Roberts Bank. Thus, although the study area defined in the Terms of Reference included the South Arm (south of the Steveston Jetty), it was considered that any discussion of the marine traffic in the South Arm had little or no relevance to pipeline construction across Roberts Bank to the south.

In light of the above, it was considered that the use of Canoe Pass should be the primary focus of investigation in terms of the potential interference construction on Roberts Bank will have on marine traffic. A review of the volume and frequency of boat traffic was undertaken, based on existing information. The Department of Highways was contacted for records of boat traffic passing under the Westham Island Bridge, as they are responsible for operating the swing span in the bridge. In addition, contact was made with several marina operators in the area, and with local fishermen. Various representatives of the Canadian Coast Guard, Pacific Pilotage Authority, Port of Vancouver, South Fraser Harbour Commission, and the Council of Marine Carriers were also contacted for comment on the project.

5.2 Traffic Volumes in Canoe Pass

There are four marinas located along the South Arm of the Fraser River between the Deas Tunnel and Brunswick Point. These are:

1. Deas Harbour Marina - immediately upstream of Deas Tunnel
2. Captains Cove Marina - immediately downstream of Deas Tunnel
3. Harbour Park Marina - Ladner
4. Wes-Del Marina - immediately downstream of Westham Island Bridge.

In general, boaters moored at the Harbour Park Marina or the Wes-Del Marina tend to be more familiar with Canoe Pass and consequently use it more frequently than those moored in other marinas. Discussion with operators at the Captains Cove Marina indicated that boaters that moor in this general location tend to avoid using Canoe Pass as they are not familiar with the channel, and therefore run a greater risk of running aground than by using the main channel via Steveston. In addition to these marinas, there are numerous boats moored along the river bank between Ladner and the Westham Island bridge, most of which are commercial fishing boats.

Traffic Volumes:

Table 5.1 summarizes traffic data for Canoe Pass based on Department of Highway's records of span openings in the Westham Island bridge in the period from March 1980 through June, 1981. Figure 6 presents a graph showing the total monthly traffic volumes and seasonal variation of use of Canoe Pass over the same time period.

The peak period of use occurs during August and September, with approximately 425 total transits (both directions) being recorded for each of these months in 1980. On a daily basis, this averaged around 14 transits per day. The winter months, December through February, represented the lowest volumes of traffic, with between 50 and 80 transits per month, and a daily average of between 1 and 3 transits per day.

Weekend traffic accounted on average for 39% of the total volumes, although this proportion varies from month to month, with September and October having the lowest proportion of weekend to midweek traffic in 1980.

As the names of the individual boats passing under the bridge are recorded, it was possible to obtain a rough estimate of the number of boats that use Canoe Pass. This ranged from a maximum of 135 boats in September to a minimum of 16 boats in January. It should be noted, however, that not all boats are accounted for in this estimate, as some of the smaller pleasure craft can pass under the Westham Island bridge without requiring the span to be opened. Discussions with Department of Highways indicated that the number of boats in this category to be very small, and is generally limited to small pleasure craft of less than approximately 20 feet in length. Boats moored at the Wes-Del marina may not be fully represented in the estimate of traffic volume as this marina is situated downstream of the bridge. Its present moorage capacity is 110 berths, most of which are occupied by pleasure craft rather than commercial fishing boats.

TABLE 5.1. BOAT TRAFFIC IN CANOE PASS, MARCH 1980 - JUNE 1981

Month	Total number of transits in both directions	Average number of transits per day	Proportion of total traffic on weekends %	Number of boats making trips
March (1980)	75	2.42	64.3	33
April	121	4.03	41.3	58
May	189	6.10	40.2	77
June	206	6.87	40.3	80
July	268	8.65	40.7	88
August	422	13.61	35.3	104
September	427	14.23	20.4	135
October	280	9.03	25.7	82
November	137	4.57	35.8	39
December	83	2.68	31.3	20
January (1981)	51	1.65	27.4	16
February	79	2.82	44.3	24
March	142	4.58	40.8	39
April	112	3.73	34.8	41
May	184	5.93	39.7	69
June	176	5.87	49.4	66
			Average = 39%	

Note: Traffic measured by recorded openings of Westham Island bridge only. Small pleasure craft are not included.

User Groups:

Broadly speaking, there are four main groups of boaters that use Canoe Pass: pleasure boaters, commercial salmon fishermen, crab fishermen, and Indian food fishermen. It should be noted, however, that these groups are not mutually exclusive, as several crab fishermen fish for salmon and visa versa.

Both commercial salmon fishermen and native food fishermen are restricted by Fisheries regulations as to the times that they are permitted to fish for salmon, as discussed in Sections 2 and 3. The commercial salmon season generally extends from mid-June through to mid-October. The vast majority of sports fishermen and pleasure boaters are active during the summer months.

Crab fishermen, therefore, have been identified as the only significant group that uses Canoe Pass on a regular basis throughout the year. As most of the crab lines tend to be concentrated along the crest of the delta foreslope along Roberts Bank, Canoe Pass provides the shortest route for crab fishermen in the Ladner area, as compared to a route around the east side of Westham Island, out the South Arm via Steveston, and southwards along Roberts Bank. It was noted in discussions with crab fishermen that not only would use of the South Arm mean a much longer journey to reach the crab lines, but that use of the South Arm was not always possible due to severe weather and tide conditions that occasionally create large waves in the channel. The same conditions do not affect Canoe Pass as it is more protected due to the presence of the Tsawwassen causeway and the Roberts Bank port jetty.[1]

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[1] E. Birch. pers. comm. 1981.

6.0 IMPACT ASSESSMENT AND CONCLUSIONS

6.1 General Perspective

As far as can be determined, impacts on public use of the Roberts Bank area would be temporary, coincident with the construction period. Construction across Roberts Bank, particularly through Canoe Pass and the approach to Brunswick Point, will cause disruption to individuals that fish, hunt, recreate in, travel through, or otherwise utilize Canoe Pass and the adjacent areas. This chapter identifies potentially significant public use impacts, and suggests means whereby those impacts could be minimized or otherwise mitigated wherever practical.

At an early stage during the study, it was recognized that long-term disturbance or loss of resources, or of the habitat that supports those resources, would have far greater implications than any temporary disturbance associated with the public's use of those resources. The primary reasons for this are that:

1. Loss of the resource or destruction of habitat could result in a long-term or permanent impact, whereas disruption to the public's use of those resources, such as hunting, fishing, and other recreational activities, would generally be limited to some portion of the construction period (approximately four months).

2. Any permanent or long-term adverse effects on the resources as a result of construction activity could have an adverse effect on the public's use of that resource. For example, if fish stocks were further depleted, this would, in turn, diminish fishing opportunities for both commercial and sports fishermen; similarly, if the marsh habitat was

> heavily impacted, this could result in long-term reduction in opportunities for hunting and non-consumptive uses of wildlife and waterfowl.

It was assumed, therefore, that preservation of natural resources, and the supporting habitats, would take precedence over most other resource concerns, and the construction schedules proposed by Monenco Pipeline Consultants Ltd. in the accompanying report, are sensitive to these concerns. The dredging window for pipeline construction has, to some extent, followed the dredging guidelines for the Fraser River and the Roberts Bank port expansion, in that February 28 has been adopted as the cut-off date for dredging in Canoe Pass during the spring. The rationale for this broadly relates to avoiding the annual downstream migration of salmon fry.

If, however, the primary aim was to minimize disruption to public use of the area, it would appear from information collected to date (see Figure 7) that the preferred construction window for the most sensitive sections in Canoe Pass and the shore approach would lie between the middle to end of March, and the middle of June. This would avoid the hunting season which closes on the 10th of March, and the commercial fishing season which usually begins around the middle of June. It also is a relatively inactive time for crab fishermen as the soft shell closure is in effect between mid-May and mid-June, or longer if required by DFO. Most traffic that uses Canoe Pass is associated with commercial and sports fishing, and would therefore not be too inconvenienced at this time of year, as compared to later in the summer and fall. Clearly, though, the spring and early summer period would be in gross conflict with other environmental considerations such as those described for fisheries resources in the accompanying report by R. U. Kistritz and Associates, which addresses aquatic issues.

6.2 Construction Activities

The various steps involved in the construction process across Roberts Bank have been described in detail in another report, and will not be repeated here.[1] From this description, it appears that the construction activity in Canoe Pass and the shore approach to Brunswick Point have greater potential to interfere with the public's activities in the area than construction across the tidal flats and at the crest of the delta foreslope. There are several basic reasons for this. Firstly, construction activity on the delta foreslope and across the tidal flats of Roberts Bank would not interfere directly with the various land-based activities such as hunting, nature observation, cycling etc. that are closely associated with the dyke and the marshes adjacent to Brunswick Point. Secondly, this portion of the construction activity would not significantly affect boat access to Georgia Strait via Canoe Pass, as construction across the flats will be between 2.5 km and 0.5 km north of the Canoe Pass channel. Thirdly, although it is recognized that the construction area on Roberts Bank would constitute a temporary obstacle to some marine traffic, it cannot seriously be considered a significant impediment to the numerous smaller craft which presumably could avoid the construction area by navigating around it. This is assuming that the construction area would be out of bounds to all vessels other than those associated with construction, that it would be clearly visible at all times, and that advance notification to mariners would be given.[2]

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[1] See: Monenco Pipeline Consultants Ltd. "Impact of Construction on the Physical Environment of Roberts Bank", 1982.

[2] Construction activity at the crest of the delta foreslope will not interfere directly with the main commercial shipping lanes in Georgia Strait which are approximately 1 km farther west.

6.3 Construction Sequences

Two construction sequences were identified by Monenco Pipeline Consultants: a landwards sequence, starting at the crest of the foreslope and proceeding towards the shore, and a seawards sequence, in the reverse direction. The basic difference, apart from the direction of progress, is in the scheduling of the various steps in the construction process.

For reasons which are discussed in the Kistritz and Monenco reports, the landwards sequence was much preferred over the seawards sequence from the perspective of ease and cost of construction, and disturbance of the physical and aquatic environments. These two sequences were then examined in terms of their relative degrees of impact an public use.

The seawards sequence would involve construction activity at Brunswick Point starting at the middle of June, and continue in Canoe Pass until roughly the middle of August for the completion of the crossing of the channel. Construction across the tidal flats and the foreslope would occur through late summer and fall. The marine pipelines would then be hydrostatically tested and tied in to the land line in mid-January; this would take roughly 12 days.

Canoe Pass would be closed to traffic for approximately 1 to 1½ months, between mid-July and the middle to end of August. This would coincide with the commercial fishing season, the peak period of activity for crab fishermen, and the peak traffic volumes in Canoe Pass, reflecting both the commercial fishing activity, and sports fishing and pleasure boating activity.

The hydrostatic testing at Brunswick Point in January would coincide with hunting and bird-watching activities, albeit for a short duration.

The landwards sequence, in contrast, would require construction through Canoe Pass from about mid-October to mid-November, continuing towards Brunswick Point, with the final tie-ins to the land pipeline completed by the end of December. Demobilization would require an additional month. Canoe Pass would be blocked to traffic for about 1½ months, from the middle of October until mid to end of November. At this time of year, however, traffic volumes in Canoe Pass have dwindled, and the commercial salmon fishing season has ended. Crab fishermen operate virtually year-round, but by December, their level of activity is greatly reduced as compared to the summer months. This scheduling would, however, coincide with the peak period of hunting and other bird-related recreation activity, particularly during November and December when construction activity would be closer to the marshes and Brunswick Point.

In conclusion, the landwards construction sequence, although requiring slightly more time than the seawards sequence for construction through Canoe Pass, is preferred, as the closure of Canoe Pass for approximately 1½ months in the late fall appears to be much less disruptive than the period of closure for the seawards sequence, in terms of the total traffic using the channel, and in terms of the types of use involved.

The preference for the landwards sequence was shared by the technical and aquatic consultants, therefore it seemed appropriate at this stage for the discussion of potential impacts on public use to address the landwards construction sequence.

6.4 Potential Impacts

6.4.1 Assumptions

Several assumptions were incorporated into the assessment of potential impacts on recreational and commercial activity in the study area.

Firstly, it is not expected that there would be any long-term or permanent effects on public use of the area once construction has been completed. The only permanent feature would be a valve station, located inside the dyke in the rough land adjacent to the Brunswick cannery. In general, then, the impacts described in this report would be temporary, and limited to the construction period or some portion thereof.

Clearly, the length of time of disruption to various activities is a key factor in the impact assessment, and this assessment is based on the construction methods and scheduling as described in the Monenco report.

It should be recognized that the proposed schedule is not necessarily the one that will be adopted, and that the impacts associated with construction would vary, depending on the construction sequence and schedule that are finally selected.

Secondly, the degree to which a given activity is important to human welfare was considered in the impact assessment. Those activities upon which people's livelihood depended, such as commercial fishing, crab harvesting and Indian food fishing, were weighted more heavily than those activities that are pursued primarily for enjoyment.

The degree to which an activity is tied to a fixed location within the study area was also considered. Thus, those activities that are less easily done elsewhere, such as hunting in the marshes adjacent to Brunswick Point were weighted more heavily in the impact assessment, as compared to sports fishing along Roberts Bank which has much more flexibility in location.

6.4.2 Commercial Fishing

Salmon Fishery: The salmon fishing season extends from mid to late June until mid-October. Assuming the landwards construction sequence, it is anticipated that most of the construction activity during this period would occur on the delta foreslope and across the tidal flats of Roberts Bank.

During full river openings, it has been estimated that up to 200 boats have been fishing on Roberts Bank between the Steveston Jetty and the Roberts Bank coal port. Fishing is usually done at depth of 3-5 fathoms (6-10 m). If a full river opening, with many boats fishing, happened to coincide with this phase of construction, it is possible that some interference would occur as a result of fishing boats or their gillnets drifting into the construction zone. In addition, service boats utilizing Canoe Pass might create congestion problems during full river openings. If, on the other hand, fishing was restricted to that area west of the Blue Line or Georgina Point Line, interference would not likely occur as construction activity would be east of the fishing limits. In any case, these risks of interference should be minimized, as it is B. C. Hydro's intent that mariners would be notified well in advance of the start of construction, and that the construction zone would be clearly visible at all times to traffic in the vicinity.

Crab Fishery: In broad terms, there are two sources of potential impact on the commercial crab fishery. Firstly, there is the possibility that crab lines situated along the delta foreslope, at depths of 1 to 15 fathoms (2-27 m), may be in conflict with construction activity in this area, as the pipes would be buried to the 23 m contour in two trenches that would be dredged on the foreslope. Construction on the delta foreslope will extend from roughly the middle of June to the middle of July, and the width of the closed area would be approximately .5 km on either side of the construction train. With adequate notification to the crab fishermen, it should be possible to remove any affected crab lines from the construction area in advance, thereby preventing loss or damage to equipment.

Secondly, the closure of Canoe Pass in the fall and winter may affect crab fishermen in the Ladner region that use Canoe Pass regularly to access crab lines on Roberts Bank. The channel would be blocked for approximately 1½ to 2 months.

There are approximately ten crab fisherman that seem to use Canoe Pass channel on a regular basis because it is a much shorter, and therefore less time consuming and less costly access route than the South Arm. Under the circumstances, it is suggested that B. C. Hydro investigate the possibility of allowing temporary access through the channel perhaps once or twice per week. If this is not practical, then it must be recognized that the closure of Canoe Pass represents an additional cost to these crab fishermen, and that some form of compensation may be necessary.

Shrimp and Groundfishery: As both shrimp and ground fishing are restricted to deeper waters off Roberts and Sturgeon Banks, for groundfish, deeper than the 50 fathom (92 m) contour, construction activity at the crest of the foreslope, where the pipes would be buried to the 23 m contour, is not likely to cause any significant inconvenience to these fishermen.

Although it is difficult to determine the level of effort involved in the harvesting of shrimp and groundfish in the vicinity of Roberts Bank, discussion with the regional fisheries officer, and comparison of 1980 catch statistics for different areas in southern B. C. waters, indicated that the Roberts Bank area is of relatively minor importance for harvesting these species.[1] In light of these considerations, pipeline construction on Roberts Bank cannot reasonably be considered to have any significant impact on trawling for shrimp or groundfish.

6.4.3 Indian Food Fishing

Indian food fishing is permitted in Canoe Pass between the middle of March and mid to end of October. The portion of Canoe Pass open for food fishing is that lying upstream of the mouth of Canoe Pass, east of a line between the western edge of Westham Island and Brunswick Point, to a line between the most easterly point of Kirkland Island and the most westerly point of Deas Island.

Assuming the landwards construction sequence, construction in Canoe Pass would not begin until the middle of October, and would be situated some distance offshore from the western limit of the Indian food fishing area. Construction activity near Brunswick Point is scheduled to occur around the beginning of November, by which time the Indian food fishery would have closed. It was concluded therefore, that construction activity would not directly interfere with the Indian food fishery, because of the differences in both the timing and location of construction and Indian food fishing in Canoe Pass.

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[1] Groundfish caught in Area 29A & 29B, 1980 was 713 metric tons, as compared to 1,440 metric tons caught in Area 18. B. C. Catch Statistics, DFO 1980.

6.4.4 Recreation

Sport Fishing: As mentioned previously, Area 29 is presently closed to the taking of Chinook salmon, and as a result, Roberts Bank receives relatively minor use as compared to other areas to the north or west. Most of the sport fishing is done in the summer months, although it is possible to fish year round.

It is difficult to imagine that construction activity would have any significant impact on sport fishing, recognizing again that the closure of Canoe Pass channel in the late fall may incur additional travelling costs for those boats that would normally use Canoe Pass to access Georgia Strait. During the summer months, construction would move inshore from the delta foreslope reaching Canoe Pass channel by mid-October. An area of roughly 1 km wide x 1.5 km long would be closed to all boats during the construction phase. This temporary obstruction on the delta foreslope and across the tidal flats during the summer can only be considered a minor inconvenience for boats that would have to navigate around it in an otherwise open area of water. In conclusion, pipeline construction across Roberts Bank would not incur any significant loss of opportunity for sport fishing, but would incur some temporary inconvenience to boaters that usually use Canoe Pass during the fall, and would be required to access Georgia Strait via the South Arm of the Fraser River.

Crabbing: Based on limited available information, it appears as if there is very little recreational crabbing in the vicinity of Brunswick Point or on the tidal flats north of Canoe Pass channel. Crabbing takes place mostly during the summer. In view of this, it was concluded that pipeline construction would have little, if any, significant impact on this activity.

Hunting: As Brunswick Point and the adjacent tidal marshes are a popular public hunting area, there would be some disruption to hunting activity in the area during the later phases of construction. Specifically, it is anticipated that the period of disruption would occur roughly between mid to late October and the end of December, at which time the pipelines would be installed in the shore approach trench, through a small section of the marsh and through the dyke to tie in with the land pipeline. This phase of construction would coincide with the prime hunting season for ducks and snowgeese.

Potential impacts on hunting would be temporary, provided that the marsh is restored, thereby minimizing the loss of habitat and long-term displacement of waterfowl. Potential impacts, therefore, relate to the direct loss of hunting opportunity if a hunting closure was imposed as a safety measure, and an indirect loss of hunting opportunity as a result of displacement of birds due to the noise and other general disturbance generated during this phase of construction.

A hunting closure would presumably only be imposed if the B. C. Fish and Wildlife Branch deemed it necessary to ensure an adequate safety buffer around the construction spread. B. C. Hydro is prepared to accept the decision of the Branch on this issue.

The construction activity would undoubtedly affect bird distribution and behaviour during the fall and winter season, with the result that there would likely be some impact on bird hunting in the affected area. It is difficult to judge the degree of impact on hunting activity, although it may result in increased hunting pressure in the Westham Island marshes or in other public hunting areas.

General Recreation: It is difficult to assess the level of potential impact on general recreational use when there is virtually no comprehensive information available documenting the nature and level of activity in the Brunswick Point/Roberts Bank area.

As discussed in Section 4.4, it would appear that recreational use other than sport fishing and boating, is closely associated with the dyke, and the marshes and channels surrounding Brunswick Point. It is reasonable to assume, therefore, that potential impacts on general recreational use would be associated with construction activity close to Brunswick Point, rather than the wide expanse of tidal flats farther offshore.

Potential impacts would involve disruption of public access along the dyke during that period when the dyke is breached, and some impairment of the recreational experience due to the presence of construction equipment, crews, etc., in an otherwise relatively tranquille and scenic setting.

Installing the pipes through the dyke and joining them to the land pipeline is expected to take approximately two weeks at the end of December. At this time of year, it is believed that the dyke and adjacent marshes would be used mainly by bird-watchers and hunters, and it is recognized that there would be some temporary inconvenience created at this time. In a broader sense, though, it is likely that construction activity would affect the distribution of birds in the area for about two to three months as the construction train moves inshore from Canoe Pass Channel, and this may, in turn, diminish both hunting and bird-watching opportunities during that time.

6.4.5 Marine Traffic

Many of the potential impacts of pipeline construction on Roberts Bank are directly or indirectly associated with boat traffic, including both commercial and pleasure craft. These impacts would be temporary, occuring as a result of partial or total obstruction of marine traffic during the construction period.

During most of the construction period, from the start of construction in mid-June on the delta foreslope until Canoe Pass is reached in mid-October, the presence of the dredge, laybarge, backfill pontoon and other associated equipment would constitute a minor inconvenience to marine traffic in the surrounding waters. The construction train would occupy a working space of roughly 200 x 500 m within a closed area of 1 km by 1½ km, and would move inshore from the crest of the foreslope across Roberts Bank towards Brunswick Point. It is assumed that boats would have minimum difficulty in avoiding the construction zone, provided that it is visible at all times. It is considered that pipeline construction across Roberts Bank would have no appreciable effect on the movement of deep sea vessels as the commercial shipping lanes within which these ships travel are west and north of the delta foreslope, as shown on Figure 3. In any case, mariners would be notified in advance of the start of construction of the project as required under the Navigable Waters Protection Act.

It was concluded, therefore, that the major effect on marine traffic would occur during the time that Canoe Pass would be closed, from mid-October until mid-December. At this time of year, the average number of total transits per day ranged from 9 in October to 2.7 in December, based on B. C. Ministry of Transportation and Highways records of openings of the Westham Island bridge span in 1980. The number of boats using the channel, recognizing that those moored at the Wes-Del Marina located downstream of the bridge may not be fully accounted for, ranged from 82 in October, 39 in November, and decreased to 20 and 16 in December and January respectively.

Judging from the records of bridge openings which provide a fairly accurate representation of traffic patterns in Canoe Pass, and through discussions with local marina operators and fishermen who are familiar with the channel, it is fairly obvious that the lowest traffic volumes in Canoe Pass occur during the winter months, especially December and January. Assuming, therefore, that the channel would be closed continously for a two month period in the late fall and winter, it was concluded that the proposed timing of the closure would have least effect on marine traffic at this time of year as compared to a closure during the spring, summer or early fall.

Closure of Canoe Pass would, however, result in some inconvenience, in terms of additional travelling time and costs, to those people who would normally choose to use Canoe Pass to access Georgia Strait. The option of travelling via the South Arm is, nevertheless, available although it clearly represents a longer route for boats stationed in the Ladner area.

As the proposed construction schedule for the Roberts Bank work may change prior to approvals being obtained, there is a definite possibility that the closure of Canoe Pass could have a different degree of impact that that described if it occurs at a different time of year. It is suggested, therefore, that once the terms and conditions for construction on Roberts Bank have been agreed, that the effort be made to more precisely determine who, and to what degree, will be affected by the closure of Canoe Pass, and if appropriate, to what extent compensation should be made to those people. From present information, it appears as if the only commercial users that stand to be affected would be crab fishermen in the Ladner area.

FIGURES

Study Area **Figure 1**

■ Fraser River

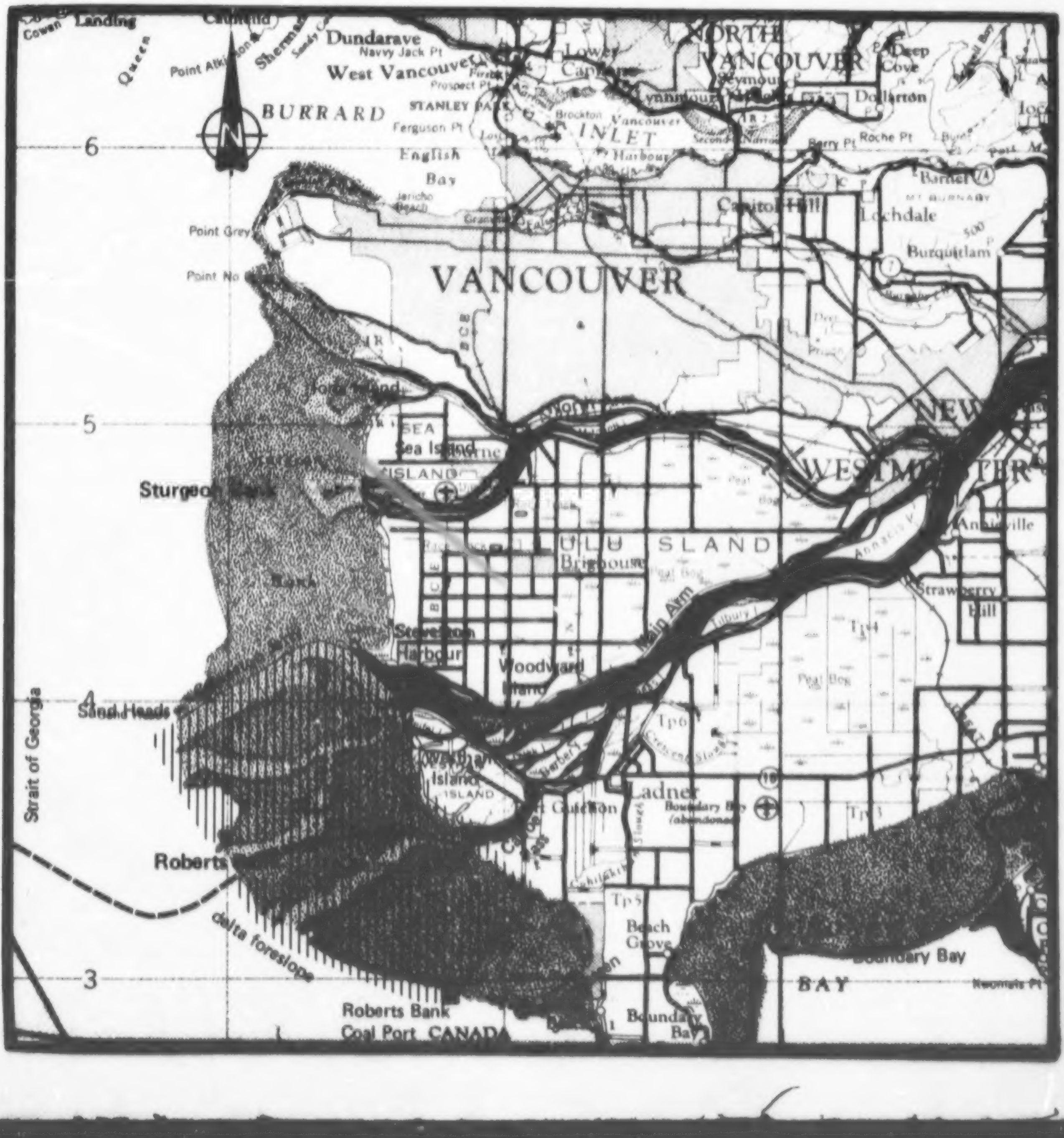
▨ Intertidal banks

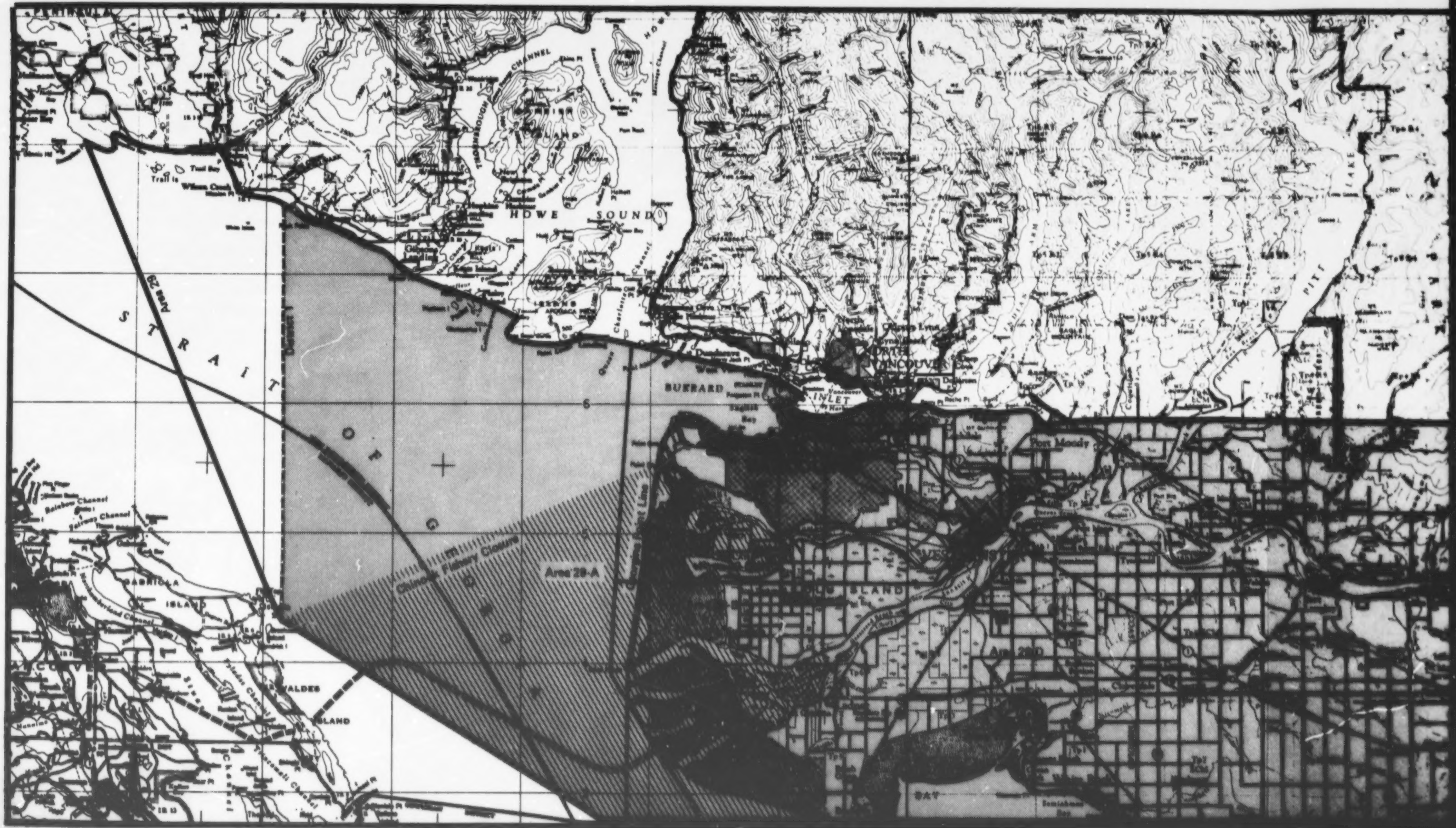
▥ Study Area

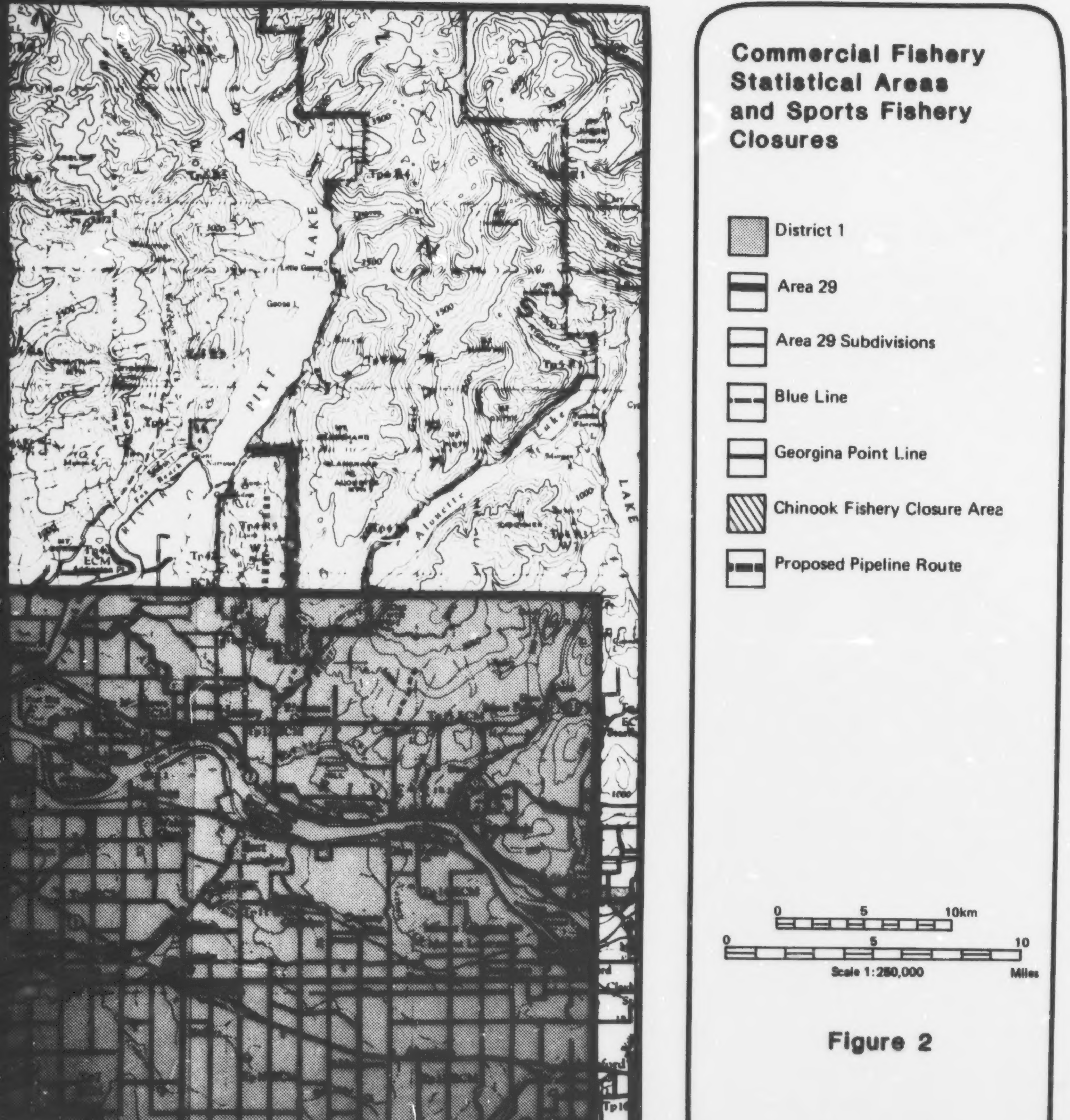
▭ Proposed Pipeline Route

0 5 10km

Scale 1:210,000

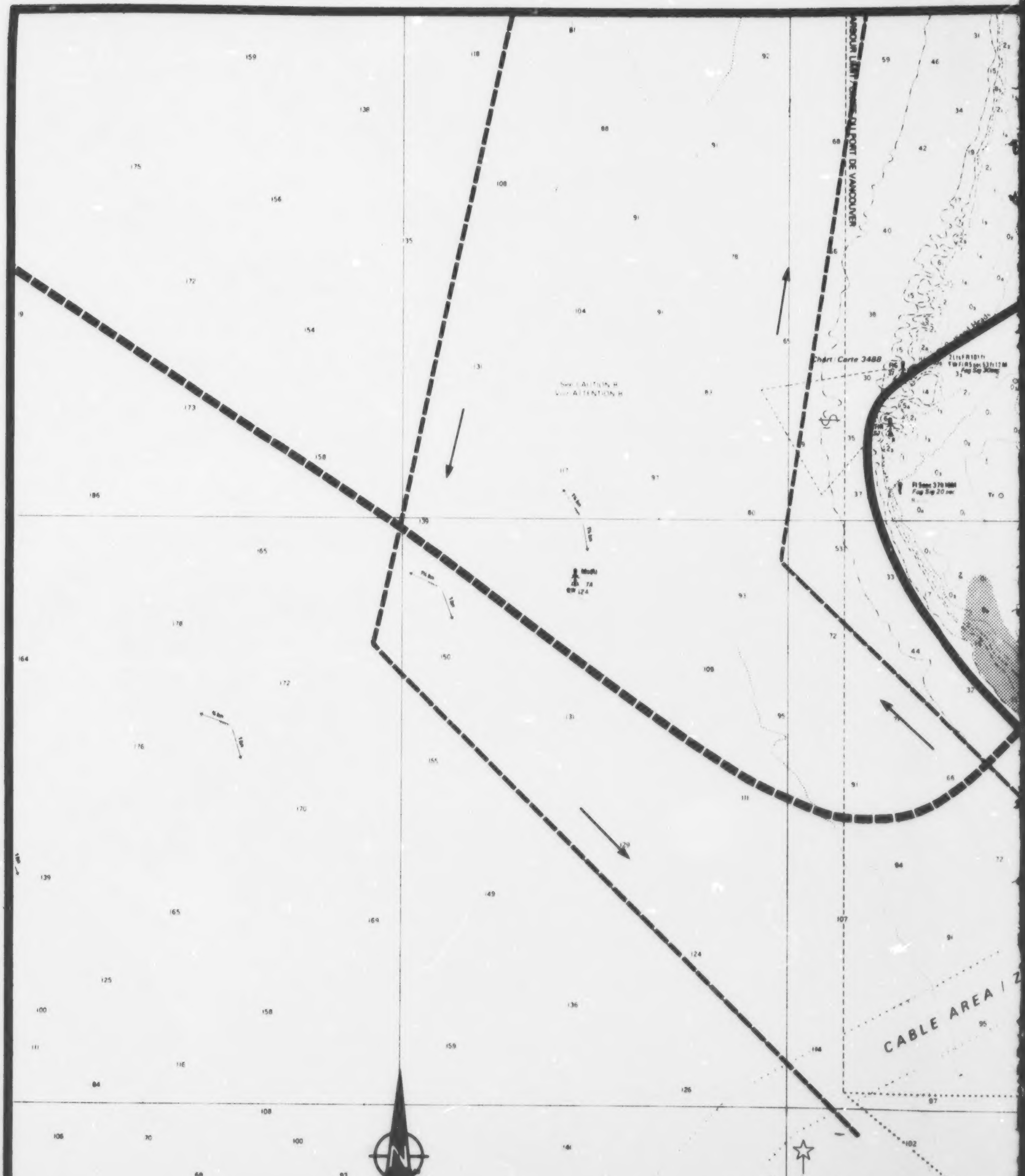

Cowan
Landing
Caulfeild
Queen
Point Atkinson
Sherman
Sandy Cove
Dundarave
Navvy Jack Pt
West Vancouver
Prospect Pt
BURRARD
N
STANLEY PARK
Brockton
INLET
Vancouver Harbour
Second Narrows
Ferguson Pt
English Bay
Jericho Beach
NORTH VANCOUVER
Lower Capilano
Seymour
Deep Cove
Dollarton
Barry Pt
Roche Pt
Barnet
MT BURNABY
Lochdale
Burquitlam
Capitol Hill
500
7
74
6
5
4
3
Point Grey
Point No Point
VANCOUVER
Iona Island
SEA ISLAND
Sea Island
Sturgeon Bank
Richmond
LULU ISLAND
Brighouse
Peat Bog
NEW WESTMINSTER
Annieville
Strawberry Hill
Main Arm
Tilbury I
Steveston
Steveston Harbour
Woodward Island
Sand Heads
Strait of Georgia
Tp6
Tp4
Tp3
Tp5
Westham Island
Ladner
Port Guichon
Boundary Bay (abandoned)
Roberts
delta foreslope
Beach Grove
Boundary Bay
BAY
Neomais Pt
Roberts Bank Coal Port
CANADA
Boundary Bay
10

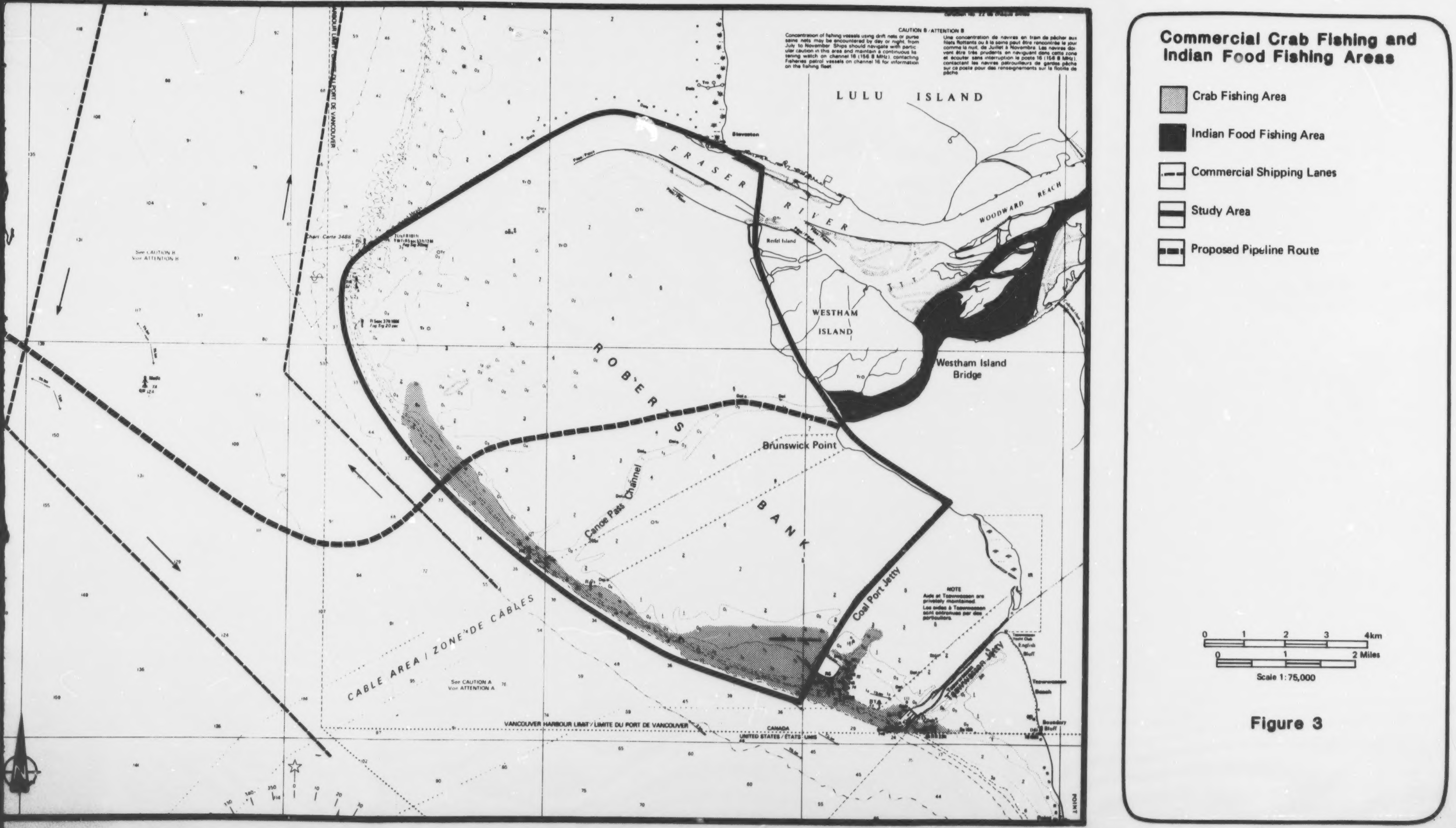

PENINSULA
Trail Bay
Trail Is
Wilson Creek
THORNBROUGH CHANNEL
HOWE SOUND
Gibsons Landing
Charlotte Channel
Area 29
STRAIT OF GEORGIA
Chinook Fishery Closure
Area 29-A
6
5
BURRARD
INLET
English Bay
Dundarave
West Vancouver
NORTH VANCOUVER
Lynn Creek
Dollarton
Port Moody
PITT LAKE
LULU ISLAND
Area 29D
BAY
Semiahmoo Bay
Rainbow Channel
Fairway Channel
GABRIOLA ISLAND
Northumberland Channel
VALDES ISLAND
Pylades Channel
Trincomali Channel
Stuart Channel
Nanaimo


PITT LAKE
Goose L.
Alouette Lake
LAKE
District 1
Area 29
Area 29 Subdivisions
Blue Line
Georgina Point Line
Chinook Fishery Closure Area
Proposed Pipeline Route
0
5
10km
0
5
10
Scale 1:250,000
Miles

Commercial Fishery Statistical Areas and Sports Fishery Closures

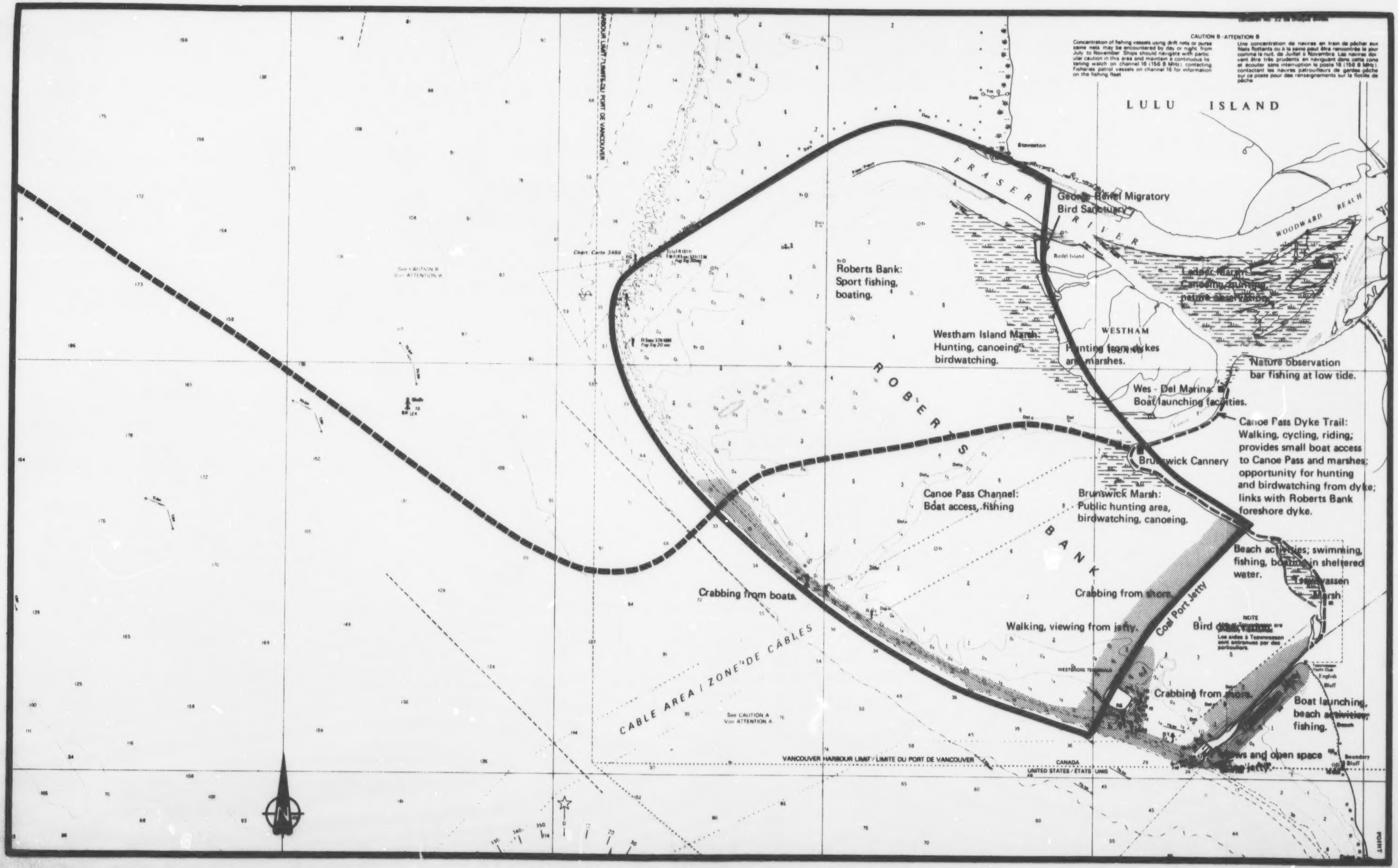
Figure 2


HARBOUR LIMIT / … DU PORT DE VANCOUVER
See CAUTION B
Voir ATTENTION B
Chart / Carte 3488
CABLE AREA / Z
Fog Sig 20 sec
N


LULU ISLAND
Steveston
FRASER RIVER
WOODWARD REACH
Reifel Island
WESTHAM ISLAND
Westham Island Bridge
ROBERTS BANK
Brunswick Point
Canoe Pass Channel
Coal Port Jetty
Tsawwassen Jetty
Tsawwassen Yacht Club
English Bluff
Tsawwassen Beach
Boundary Bluff
CABLE AREA / ZONE DE CABLES
Chart / Carte 3488
See CAUTION B / Voir ATTENTION B
See CAUTION A / Voir ATTENTION A
VANCOUVER HARBOUR LIMIT / LIMITE DU PORT DE VANCOUVER
CANADA
UNITED STATES / ÉTATS-UNIS
CAUTION B / ATTENTION B
Concentration of fishing vessels using drift nets or purse seine nets may be encountered by day or night, from July to November. Ships should navigate with particular caution in this area and maintain a continuous listening watch on channel 16 (156.8 MHz), contacting Fisheries patrol vessels on channel 16 for information on the fishing fleet.
Une concentration de navires en train de pêcher aux filets flottants ou à la seine peut être rencontrée le jour comme la nuit, de Juillet à Novembre. Les navires doivent être très prudents en naviguant dans cette zone et écouter sans interruption le poste 16 (156.8 MHz), contactant les navires patrouilleurs de gardes pêche sur ce poste pour des renseignements sur la flotille de pêche.
NOTE
Aids at Tsawwassen are privately maintained.
Les aides à Tsawwassen sont entretenues par des particuliers.
▨ Crab Fishing Area
■ Indian Food Fishing Area
Commercial Shipping Lanes
Study Area
Proposed Pipeline Route
0 1 2 3 4km
0 1 2 Miles
Scale 1:75,000

Commercial Crab Fishing and Indian Food Fishing Areas

Figure 3


CAUTION B · ATTENTION B
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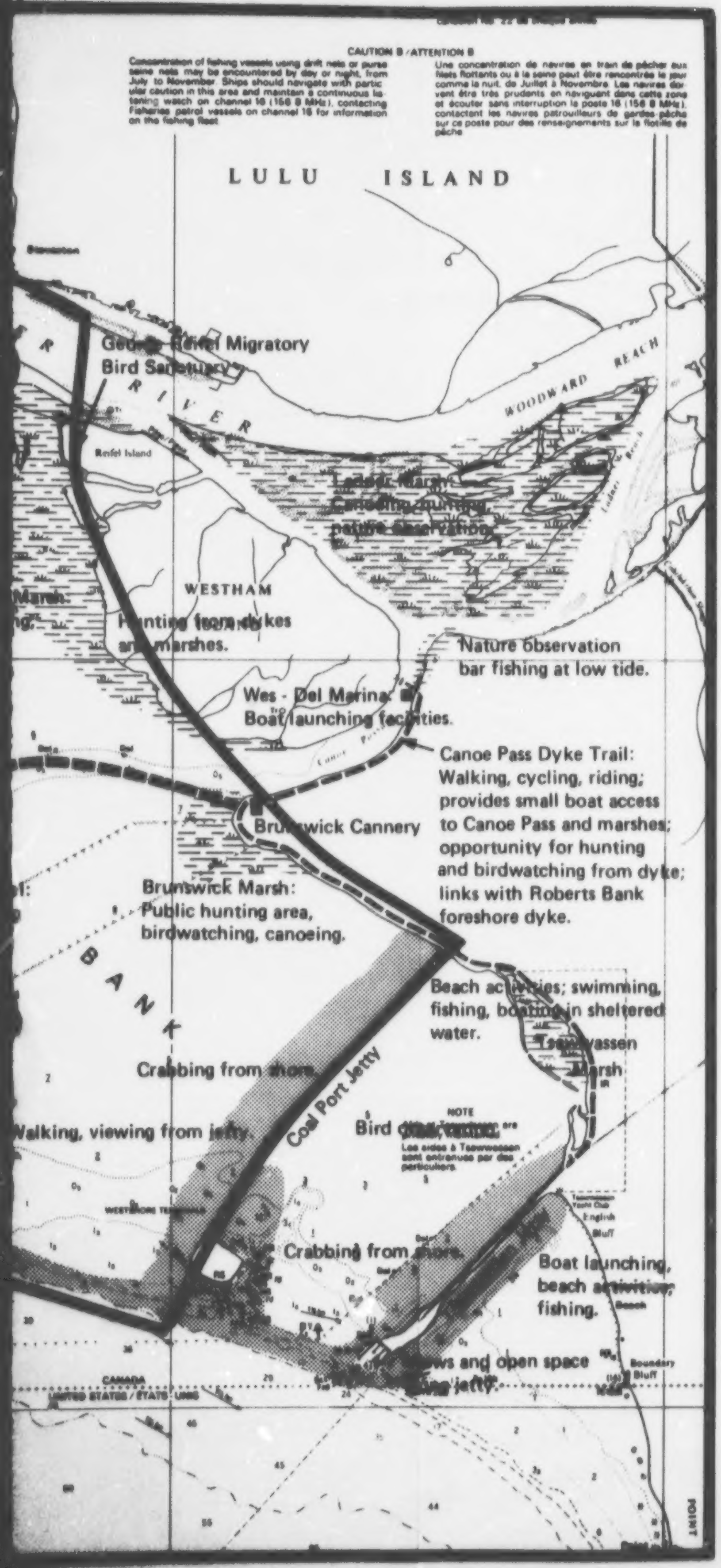
LULU ISLAND
Steveston
FRASER RIVER
WOODWARD REACH
George Reifel Migratory Bird Sanctuary
Reifel Island
Ladner Marsh: Canoeing, hunting, nature observation.
Roberts Bank: Sport fishing, boating.
Westham Island Marsh: Hunting, canoeing, birdwatching.
WESTHAM
Hunting from dykes and marshes.
Nature observation bar fishing at low tide.
Wes - Del Marina: Boat launching facilities.
Canoe Pass Dyke Trail: Walking, cycling, riding; provides small boat access to Canoe Pass and marshes; opportunity for hunting and birdwatching from dyke; links with Roberts Bank foreshore dyke.
Brunswick Cannery
ROBERTS BANK
Canoe Pass Channel: Boat access, fishing
Brunswick Marsh: Public hunting area, birdwatching, canoeing.
Beach activities; swimming, fishing, boating in sheltered water.
Tsawwassen Marsh
Crabbing from shore.
Coal Port Jetty
Walking, viewing from jetty.
Bird observation.
NOTE
Les aides à Tsawwassen sont entravues par des particuliers.
Crabbing from boats.
Crabbing from shore.
WESTSHORE TERMINALS
Tsawwassen Yacht Club
English Bluff
Boat launching, beach activities, fishing.
Beach
Views and open space along jetty.
Boundary Bluff
CABLE AREA / ZONE DE CÂBLES
See CAUTION A
Voir ATTENTION A
See CAUTION B
Voir ATTENTION B
Chart · Carte 3488
VANCOUVER HARBOUR LIMIT / LIMITE DU PORT DE VANCOUVER
CANADA
UNITED STATES / ÉTATS-UNIS
POINT
Rec
Rob


CAUTION B / ATTENTION B
Concentration of fishing vessels using drift nets or purse seine nets may be encountered by day or night, from July to November. Ships should navigate with particular caution in this area and maintain a continuous listening watch on channel 16 (156.8 MHz), contacting Fisheries patrol vessels on channel 16 for information on the fishing fleet.
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LULU ISLAND
George Reifel Migratory Bird Sanctuary
RIVER
Reifel Island
WOODWARD REACH
Ladner Marsh: Canoeing, hunting, nature observation.
WESTHAM
Hunting from dykes and marshes.
Nature observation bar fishing at low tide.
Wes - Del Marina: Boat launching facilities.
Canoe Pass
Canoe Pass Dyke Trail: Walking, cycling, riding; provides small boat access to Canoe Pass and marshes; opportunity for hunting and birdwatching from dyke; links with Roberts Bank foreshore dyke.
Brunswick Cannery
Brunswick Marsh: Public hunting area, birdwatching, canoeing.
BANK
Beach activities; swimming, fishing, boating in sheltered water.
Tsawwassen Marsh
Crabbing from shore.
Coal Port Jetty
Walking, viewing from jetty.
Bird observation
NOTE
Les eaux à Tsawwassen sont entourées par des particuliers
WESTSHORE TERMINALS
Crabbing from shore.
Boat launching, beach activities, fishing.
English Bluff
Beach
Views and open space along jetty.
Boundary Bluff
CANADA
UNITED STATES / ÉTATS-UNIS
POINT

Recreation Activities on Roberts Bank

▨ Marsh Area
▨ Crabbing Area
- - - Dyke Trail
■ Specified Facility
▬ Study Area
▬ ▬ Proposed Pipeline Route
0 1 2 3 4km
0 1 2 Miles
Scale 1:75,000

Figure 4

Westham Island and Brunswick Marshes

Figure 5

▤ Marsh Area

╌ Proposed Pipeline Route

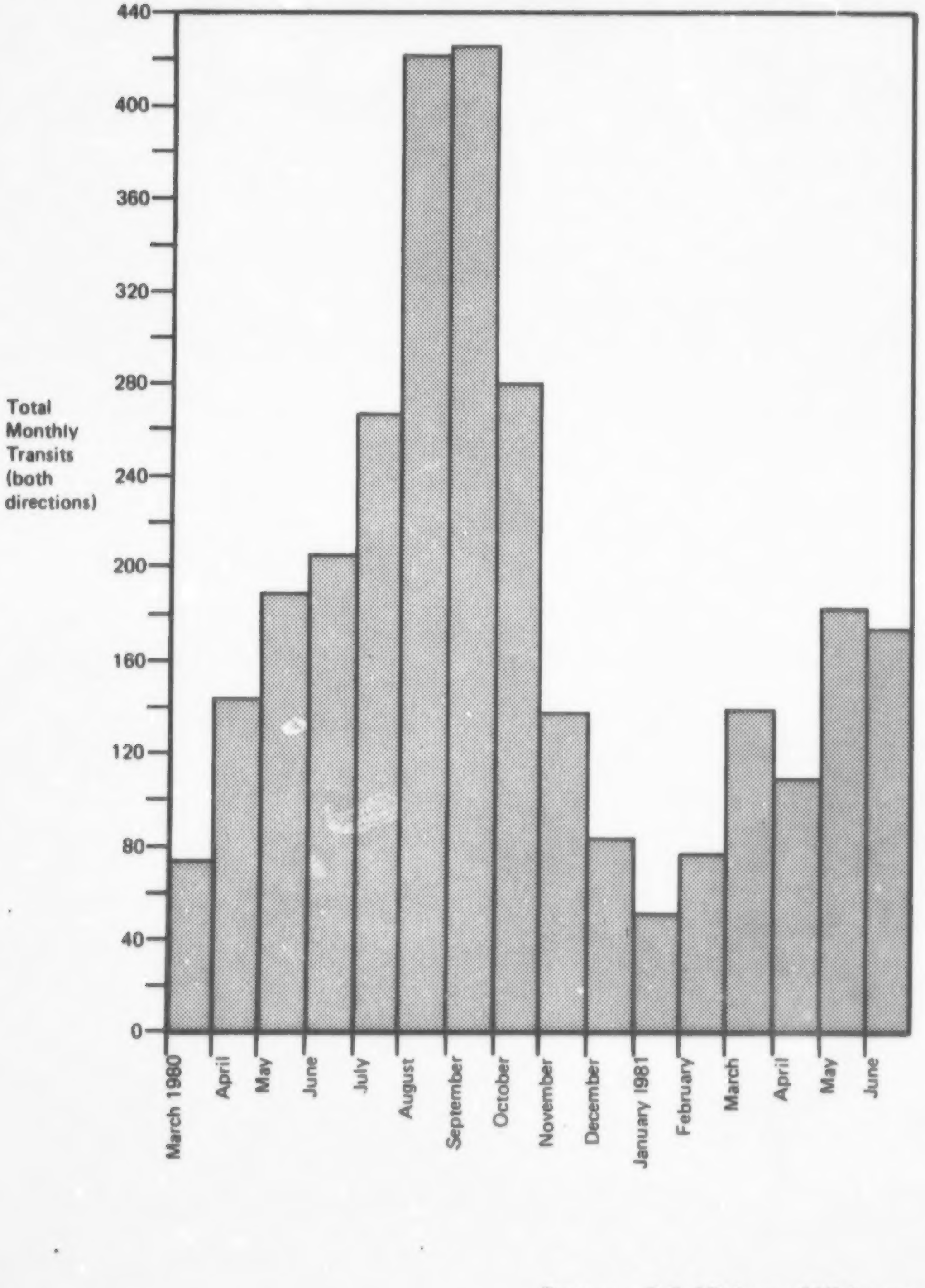
0 1 2km

0 1 2 Miles

Scale 1:72,000

Figure 6

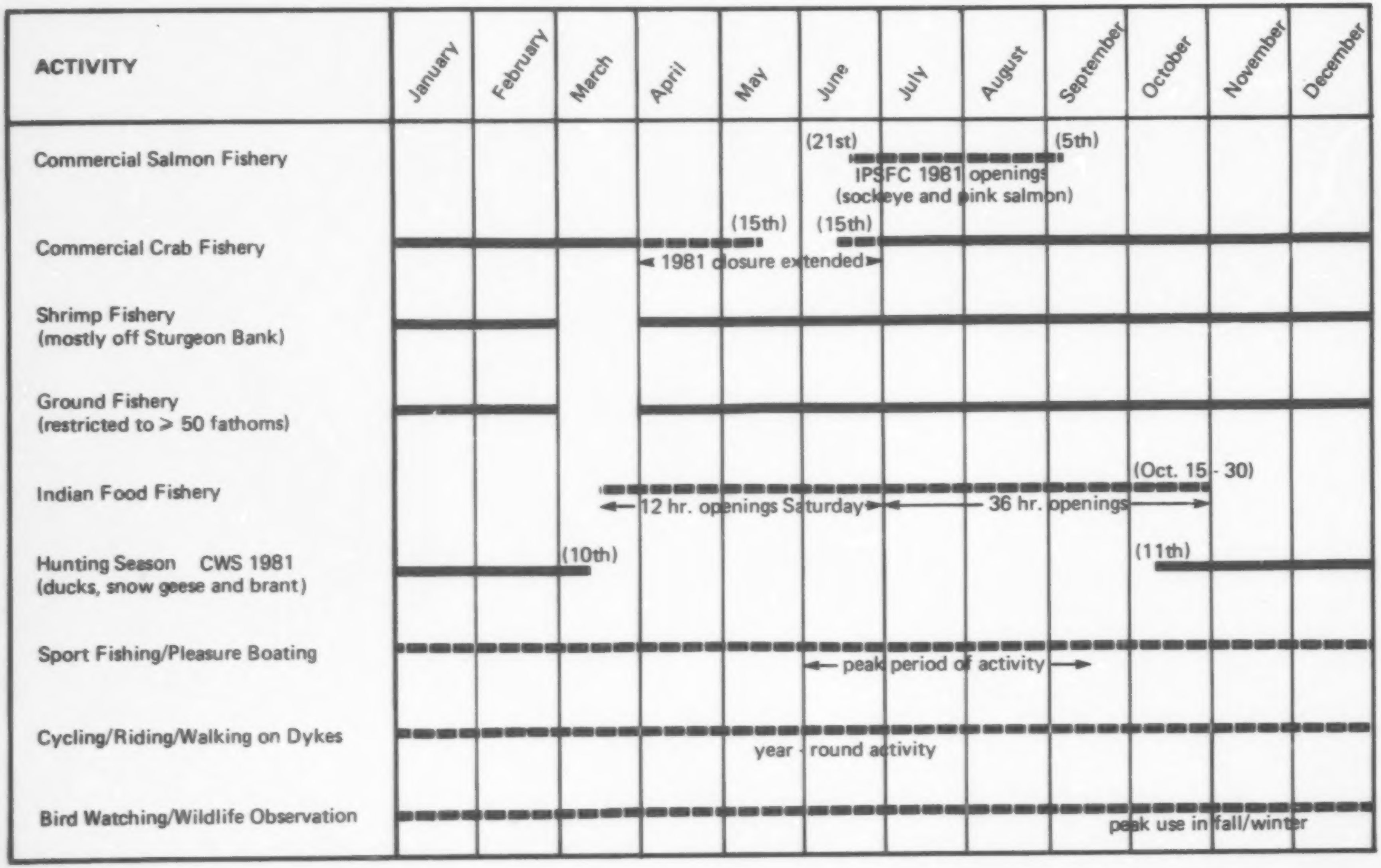
BOAT TRAFFIC VOLUMES IN CANOE PASS



Source: B.C. Ministry of Highways,
Westham Island Bridge Span Openings,
1980 - 1981

Figure 7

ROBERTS BANK SEASONAL ACTIVITIES



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